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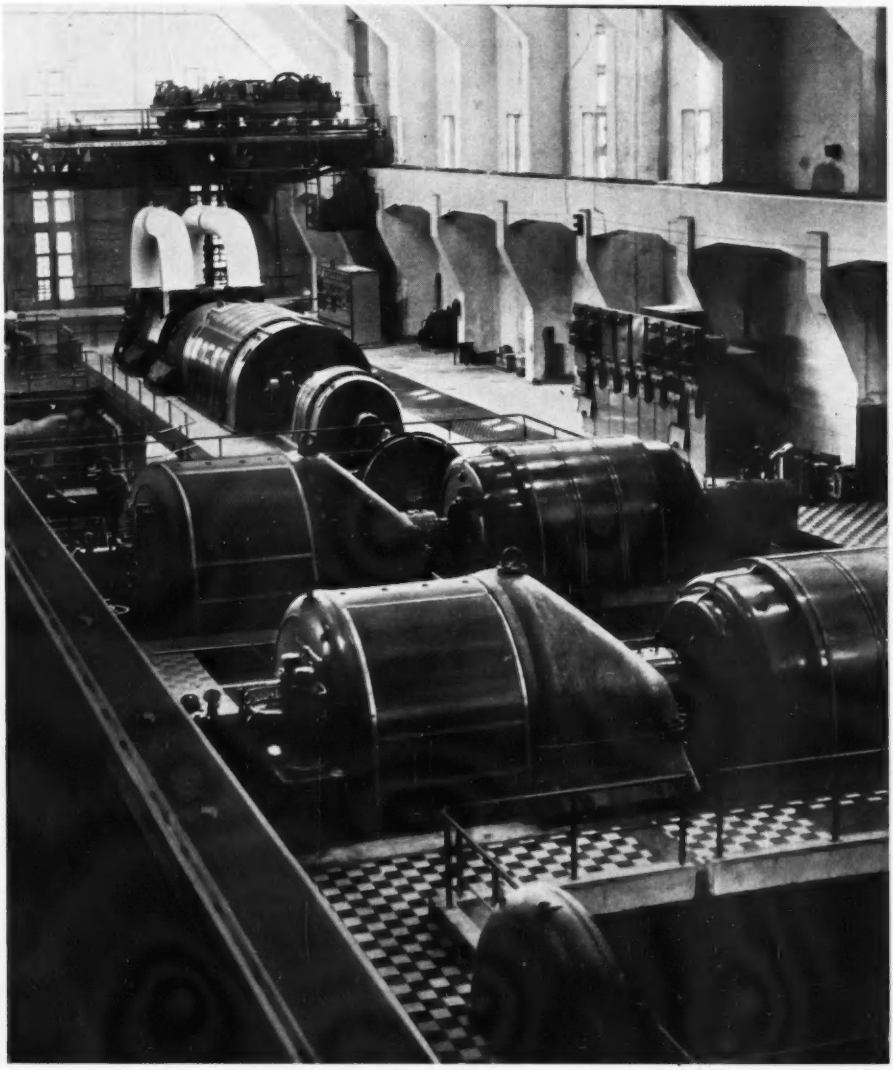

THE HAIFA NEW POWER STATION OF THE PALESTINE ELECTRIC CORPORATION.

There will be five sets in this station with a total capacity of 117,500 kVA. One of the 40,000 kVA turbo-alternators is seen in the background ; a further set of the same rating is now being built.

Control Gear for Fluorescent Lamps

By S. ANDERSON, B.Sc., A.M.I.E.E.
Chief Lighting Engineer.

Satisfactory operation of fluorescent lamps is dependent upon the associated control gear.

In this article the electrical characteristics of hot cathode lamps and of the control gear are described; the performance of control gear is discussed and various designs are illustrated.

In view of the wide variety of control gear now available, it is important that those concerned with its choice and use should be aware of the factors involved in suitable design and performance.

INTRODUCTION.

IT is now ten years since hot cathode fluorescent lamps were first introduced. Since becoming generally available some six years ago they have been applied in ever-widening variety and in situations which now comprise nearly the whole field of artificial lighting.

They constitute the only form of electric light source not suitable for direct connection to the mains which have achieved such popularity. By comparison, the carbon arc, low and high pressure mercury discharge lamps, and the sodium vapour discharge lamp have attained a far more limited popularity, due principally to the fact that for many purposes they have characteristics which render them less suitable than incandescent filament lamps.

Initially, the 5 ft. 80 watt fluorescent lamp was operated through control gear designed for the high pressure mercury lamp of the same wattage because such gear was already available and served the purpose well enough at a time when all possible development work was directed into channels vital to national defence. But as time went on, new designs of control gear appeared, made to meet more completely the particular requirements of the fluorescent lamp and its associated fittings, to suit new sizes, and to provide additional or alternative ways of starting and operating the lamp.

So many different types and sizes of control gear are now available that it must be very difficult for the prospective user to make the best choice. Having chosen, a knowledge of the considerations involved in getting good service from the control gear and of obtaining the best performance from the lamp, is very desirable.

To deal at all exhaustively with the subject would be beyond the scope of this article, but it is hoped that the material which follows will prove of interest to engineers and others who have to deal with fluorescent lighting.

LAMP CHARACTERISTICS

The mechanism of the hot cathode lamp and its general characteristics have been given elsewhere,[1] but it may be convenient to mention here those features which have a particular bearing on the design and performance of the control gear. It must be made clear that in this article only the common type of lamp with preheated or " hot starting " cathodes is considered. For the cold starting hot cathode lamp the requirements of the gear are somewhat modified.

The supply voltage necessary to operate the lamp is dependent, among other factors, upon the length of the discharge path between the electrodes. Thus the 3 ft., 4 ft. and 5 ft. lamps are normally regarded as requiring a minimum nominal supply voltage of 200, while the 2 ft. and shorter lamps are regarded as requiring about 100 volts when operated singly. The influence of the margin between the potential drop in the lamp and the supply voltage will be discussed later, but the values are given above because in considering the starting requirements of a lamp it must be realised that when simply connected through a plain series impedance to an electric supply of the normal operating value, the lamp is unlikely to start.

[1] *G.E.C. Journal*, Vol. XIII, No. 4, August, 1945.

STARTING.

In order to make the lamp start with certainty and without serious disruption of the cathodes, these must be pre-heated to a temperature at which they emit electrons copiously. When in this condition, the voltage which is necessary to start the lamp is not very much greater than the normal supply voltage, provided that it is maintained between the electrodes for a sufficient time. Where the starting voltage is in the form of a pulse of a few microseconds' duration, the peak voltage of the pulse may need to be three or four times the nominal supply voltage to ensure starting.

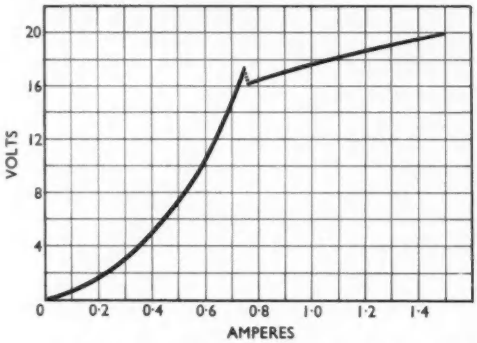

Fig. 1.—Typical voltage/current characteristic for a pair of 80 watt cathodes.

The minimum maintained voltage between the cathodes of a given size of lamp which is necessary for starting after the cathodes have reached emission temperature is found to vary quite widely and is influenced by ambient temperature and humidity. For the present purpose it is sufficient to state that the minimum maintained reliable starting voltage results when the outside of the lamp tube is in intimate contact with an earthed conductor throughout its length. Lamps with an earthing strip built in are available and are called instant-start lamps. For 5 ft. lamps the nominal maintained voltage necessary is about 220 volts r.m.s. while for 4 ft. and 3 ft. lamps 200 volts are sufficient.

A typical voltage/current relation for the two cathodes of a 5 ft. lamp connected in series is shown in fig. 1. The break in the curve occurs when the ionisation potential across the ends of each cathode is reached and a local discharge is initiated. Once this cathode discharge state has been achieved no advantage is gained by passing a heavier current through the electrodes during starting provided that the current persists for a sufficient time. Excessive pre-heating current will shorten the life of the cathodes.

Though small, the electrodes have an appreciable mass. The pre-heating current must therefore flow for an appreciable time, varying inversely with the magnitude of the current squared in order to heat the electrodes to an adequate temperature. Thus in circuits employing a glow or thermal starter it is necessary to relate the starting current passed by the control impedance to the time during which the pre-heating circuit is completed by the starter contacts. In switchless starting circuits, where the cathode pre-heating current and the starting voltage across the lamp are both applied continuously, the adequate pre-heating time is determined automatically because the lamp starts as soon as the conditions are favourable. This is assuming that a sufficient cathode pre-heating current is provided and excessive starting voltage is not applied.

OPERATING.

As soon as the main discharge has been initiated, the current through the lamp comes under the control of the series impedance. Fig. 2 shows the relation between the current in a lamp and the voltage across it when the supply voltage is held constant and the series impedance varied. Fig. 3 shows the supply voltage/lamp current relationship when the impedance remains the same and the supply voltage is varied. In fig. 2a the cathodes were maintained at an

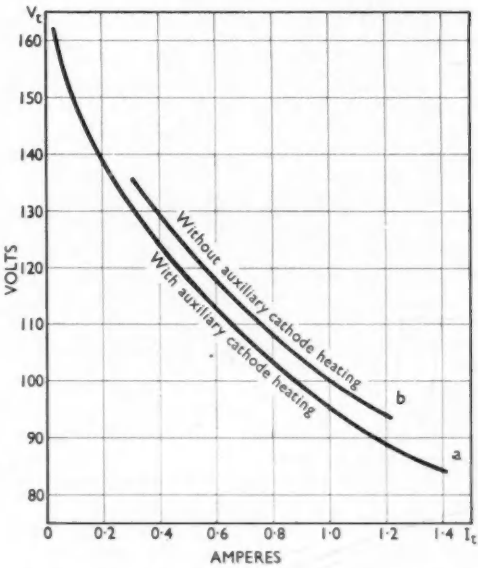

Fig. 2.—Typical voltage/current characteristics for 80 watt lamp.

operating temperature independently to avoid the extinguishing effect of the cooling electrodes which otherwise occurs with reduced arc current. This is shown in fig. 2b where the electrodes were heated only due to the passage of the discharge current, and the lamp extinguished at 0·3 amp.

From these curves it is evident that to operate a fluorescent lamp stably from a supply at constant pressure a series impedance is essential. In the absence of a current limiting device, owing to the decrease in effective lamp resistance with increasing lamp current, the latter would rise very rapidly until the electrodes disintegrated or a lead seal cracked, allowing air to enter and extinguish the lamp. In view of its function this impedance is often referred to as a ballast, but the term may include other items such as a transformer and a power factor correction capacitor, particularly when these are contained in a common housing with the control impedance.

The function of the control gear is therefore to provide suitable conditions for the lamp to start and operate without further attention once the supply has been switched on. This involves pre-heating the cathodes, applying a suitable voltage between the electrodes long enough to start the main discharge, and holding the discharge current at the appropriate value. Where the ballast is inductive, the shunt capacitor placed across the supply terminals to raise the power factor is usually regarded as part of the control gear, although strictly this capacitor has no part in the control of the lamp.

Fig. 4 shows the relationship between lamp current and lamp wattage for a 5 ft. lamp with normal inductive control.

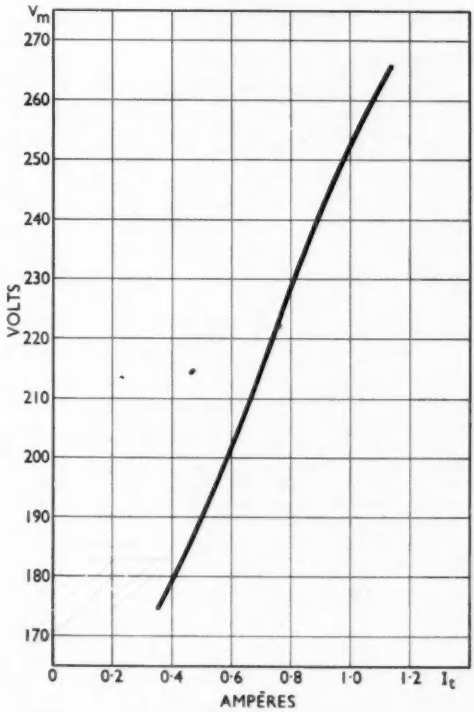

Fig. 3.—Typical supply voltage/lamp current characteristic for 80 watt lamp, using choke control designed for 230/240 volt supplies.

TABLE 1.

NOMINAL LAMP VOLTAGES AND LAMP CURRENTS FOR VARIOUS LAMPS IN FREE AIR AT 20 DEGS. C.

LAMP		D.C.		50 c/s A.C.	
Wattage	Size—ins.	V_t	I_t	V_t	I_t
8	12 × $\frac{5}{8}$	61V	·13A	54V	·17A
14	15 × 1½	44	·32	41	·39
15	18 × 1	60	·25	56	·32
20	24 × 1½	65	·31	62	·35
30	36 × 1	110	·27	103	·35
40	24 × 1½	53	·76	50	·85
40	48 × 1½	117	·34	108	·41
80	60 × 1½	114	·7	106	·85
125	96 × 1½	—	—	170	·85

Table 1 gives the normal operating current and potential across the lamp for D.C. and 50 cycle A.C. working when the lamp is operated at nominal wattage and in an ambient temperature of 20 degs. C. in free air. It will be noticed that on D.C. the voltage across the lamp is somewhat higher and the arc current lower than on A.C. On D.C. the product of these values is equal to the lamp wattage, but on A.C. their product is some 10 per cent higher than the true lamp wattage. Both lamp current and lamp voltage waves pass through their zero values coincidentally and in this sense therefore the lamp power factor is unity, but due to their departure from sinusoidal form the product of r.m.s. lamp current and voltage is greater than the lamp wattage, and fluorescent lamps supplied with alternating current are therefore regarded as having a power-factor which is slightly less than unity.

Since the characteristics of the ballast have an influence on the wave-form of the current in the lamp it will be appreciated that the values quoted in Table 1 may not always apply. They refer to lamps controlled by well-designed reactive ballasts giving the highest practical lamp power factor. With resistive ballasts the lamp current

wave-form and power factor are poor so that for rated wattage the r.m.s. current is appreciably higher.

The effect of ambient temperatures considerably above or below 20 degs. C. is to vary the lamp characteristics due to the consequent variation in mercury vapour pressure within the lamp.

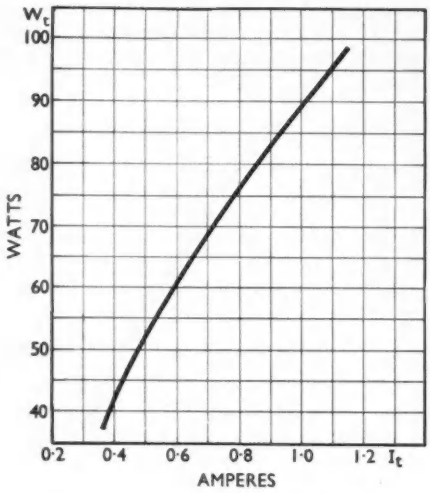

Fig. 4.—Typical current watts characteristic for 80 watt lamp, using choke control.

At sub-normal temperatures down to 5 degs. C. the lamp current is reduced and its voltage raised. This effect is seldom more than a temporary one, however, because in cold or exposed situations it is always recommended that the lamp be operated in an enclosure so that the air surrounding it is gradually warmed up by the heat generated. This is desirable not only to obtain normal electrical characteristics, but also to obtain normal light output, for at low temperatures the efficiency of the lamp is considerably reduced.

Where the ambient temperature is high, the lamp current rises and the voltage falls. With a ballast rated for normal operation, when the ambient temperature is raised to 50 degs. C. the current may rise by as much as 30 per cent. Such an increase in current may have an adverse effect on the life of the lamp and is bound to increase the operating temperature of the ballast. Both effects are undesirable and, since it is not normally practical to cool the air surrounding the lamp, it is good practice in such cases to use a ballast which on the supply voltage concerned would normally operate the lamp at a reduced current—i.e. a ballast designed for a higher supply voltage.

The figures given for 50 cycles A.C. in Table 1 are reasonably applicable over the normal range of power frequencies, although there is a small variation over this range. Where the frequency is much higher, however, a marked change takes place. The current rises, the lamp voltage falls and the wave-forms of both become more nearly sinusoidal. Thus for frequencies which are considerably in excess of 50 cycles the lamp data given are inapplicable. A typical relationship between lamp impedance and frequency is shown in fig. 5. Here the D.C. case has been included as equivalent to zero frequency. It will be seen that the fall in impedance is quite rapid with increasing frequency up to the region of 200 cycles, but in the region above 400 cycles the fall is relatively small and nearly constant in rate.

RESISTIVE CONTROL.

The simplest method of holding the fluorescent lamp current at an appropriate value is to connect in series with it a wire-wound or other pure resistance such as a tungsten filament lamp. Where the supply is direct current this is the only suitable ballast, but it has two important disadvantages. A resistive ballast for a 4 ft. 40 watt or 80 watt lamp dissipates power roughly similar in magnitude to that used in the fluorescent lamp, as shown in Table 2. Thus the overall efficiency in terms of lumens per watt used is only about half that of the fluorescent lamp alone.

TABLE 2.

POWER LOSS IN RESISTIVE BALLASTS FOR VARIOUS LAMPS OPERATED ON D.C. SUPPLIES

Supply Voltage	100	110	120	200	230	250
Lamp	Approximate loss in ballast—watts					
15W 18 ins.	10	12	15	35	42	47
20W 24 ins.	11	14	17	42	51	57
30W 36 ins.	—	—	—	24	32	38
40W 24 ins.	36	43	51	112	134	150
40W 48 ins.	—	—	—	28	38	45
80W 60 ins.	—	—	—	60	81	95

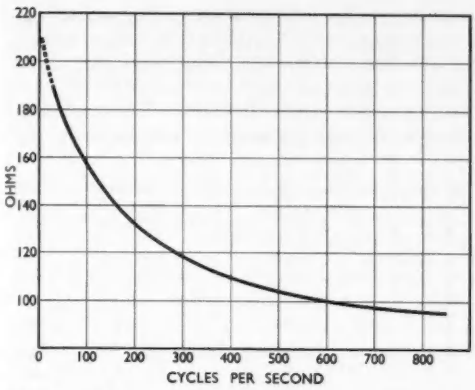

Fig. 5.—Effective impedance/frequency characteristic for 2 ft. 20 watt lamp.

Table 2 also shows that it is quite impractical to operate the shorter fluorescent lamps singly on 200/250 volts D.C. since here the losses are far larger than the power expended in the fluorescent lamp. The other disadvantage is that a pure resistive ballast provides no facility for generating the high voltage surge used to start the longer hot cathode lamps in a normal switch-start circuit.

The way in which glow and thermal starters operate has been dealt with elsewhere[1] but it is sufficient here to point out that the generation of a surge voltage in the circuit when the cathode pre-heating current is interrupted is dependent on the inclusion of a sufficient inductance in the circuit. With resistive control, therefore, it is still necessary on D.C. mains, and it may be desirable on A.C., to include a choke coil, though this can be smaller and is less critical in its characteristics than where the choke constitutes the whole of the ballast impedance.

The choke included in a resistive ballast circuit for D.C. will have an appreciable D.C. resistance and this should be taken into account in deciding the value of ballast resistor to be used in a specific case. The resistance values given in Table 3 should have the resistance of the choke subtracted to give the value of the actual ballast resistance required. Resistance ballasts may be

[1] *G.E.C. Journal*, Vol. XIII, No. 4, August, 1945. *Electrical Times*, June 9th, 1949, p. 763.

TABLE 3.

BALLAST RESISTANCE VALUES IN OHMS FOR VARIOUS LAMPS OPERATED ON D.C. SUPPLIES.

Supply Voltage	100	105	110	115	120	125	200	210	220	230	240	250
Lamps												
1. 8W 12 ins. × $\frac{5}{8}$ ins.	250	287	324	362	400	438						
2. 8W 12 ins. × $\frac{5}{8}$ ins.							500	554	648	724	800	876
1. 14W 15 ins. × 1$\frac{1}{2}$ ins.	162	179	196	214	232	250						
1. 15W 18 ins. × 1 in.	125	145	165	185	205	225						
2. 15W 18 ins. × 1 in.							250	290	330	370	410	450
1. 20W 24 ins. × 1$\frac{1}{2}$ ins.	100	116	132	148	164	180						
2. 20W 24 ins. × 1$\frac{1}{2}$ ins.							200	232	264	296	328	360
1. 30W 36 ins. × 1 in.							305	342	379	416	453	490
1. 40W 24 ins. × 1$\frac{1}{2}$ ins.	62	68	75	81	88	95						
2. 40W 24 ins. × 1$\frac{1}{2}$ ins.							124	137	150	163	176	190
1. 40W 48 ins. × 1$\frac{1}{2}$ ins.							226	250	274	298	323	348
1. 80W 60 ins. × 1$\frac{1}{2}$ ins.							112	126	140	154	168	182

NOTE.

Where two lamps are indicated in the left-hand column, the resistances quoted are values suitable for the two lamps connected in series. Values given are for the total resistance in the circuit, and the D.C. resistance of the choke plus starter should be subtracted in order to obtain the actual value of resistance required.

In practice compromise values differing slightly from those given above are sometimes used to reduce the number of different sizes required to cover a range of lamps and voltages.

called upon to carry up to 50 per cent above the normal lamp current on D.C. under continuous cathode pre-heating conditions such as may occur if a starter becomes stuck with its contacts closed or at the end of the life of the lamp when one or both electrodes are de-activated. They should be of ample size and have adequate ventilation therefore. Their life will normally be at least as long as that of the fittings used in the installation.

Owing to the heat generated in resistance ballasts it is not normally satisfactory to enclose them in the housing usually provided in fittings for reactive control gear. They may be mounted on top of a pendant fitting, but in many cases it is more convenient to place them remote from the fittings. A heat-resisting plate of sindanyo or similar material is normally provided to protect the surface to which the resistance is fixed.

Filament Lamp Ballast.

Filament lamps may be used for ballast purposes and their resistance/current characteristic (fig. 6) has some value, not afforded by the wire wound resistance, in preserving a more nearly constant current under varying supply voltage conditions. Another attractive feature is that some of the power dissipated may be converted into light which can be used to blend with that from the fluorescent lamp to give a warmer tone and some improvement in total lumens per watt. In order to obtain the maximum light output from the ballast lamp and to operate the fluorescent lamp at a suitable current, it is necessary to employ special filament lamps of non-standard ratings, and calculated examples for 4 ft. and 3 ft. lamps on A.C. supplies are given in Table 4. Starting with this type of ballast is dealt with later.

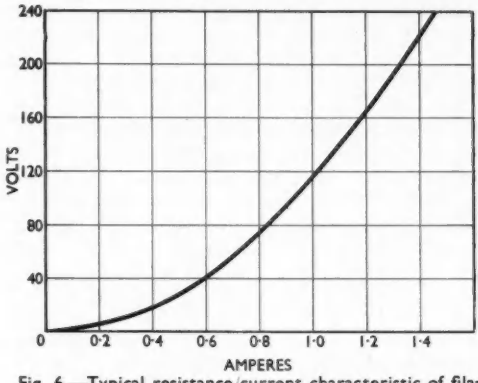

Fig. 6.—Typical resistance/current characteristic of filament lamp ballast. The curve refers to two 210 volt 150 watt lamps in parallel, suitable for use with an 80 watt fluorescent lamp on 200/210 volt A.C.

In the normal switch-start circuit the ballast lamps must withstand the higher starting current of the fluorescent lamp unless auxiliary means for reducing this to little more than the normal operating value are provided. To avoid a short life, filament ballast lamps therefore contribute only a small proportion of the total light output. In certain new circuits for A.C. operation this difficulty has been overcome.

TABLE 4.

DATA ON FLUORESCENT LAMPS WITH FILAMENT LAMP BALLAST ON A.C. SUPPLIES.

Fluorescent Lamp		30W 36 ins. × 1 in.			40W 48 ins. × 1½ ins.		
A.C. Supply Voltage		200	230	250	200	230	250
Nominal rating of special tungsten ballast lamp	Volts	124	162	188	127	154	177
	Watts	57	74	85	66	80	92
Operating conditions of special ballast lamp	Watts	43	55	64	59	72	82
	Lumens	291	380	438	650	780	900
Operating conditions of fluorescent lamp	Watts	27	27	27	40	40	40
	Lumens	1,135	1,135	1,135	1,600	1,600	1,600
Fluorescent lamp plus ballast lamp total (service values)	Lumens	1,426	1,515	1,573	2,250	2,380	2,500
	Watts	70	82	91	99	112	122
	L/W	20	18	17	23	21	20

NOTE.

The above figures are based on a ballast lamp life comparable with that of the fluorescent lamp, and are estimated.

A selection of recommended ratings of commonly available lamps for ballast purposes on D.C. supplies is given in Table 5. Since they are only run at something of the order of full voltage during starting, these ballast lamps may be expected to have a life at least comparable with that of the fluorescent lamp which they control, but they give a negligible amount of light except during starting.

TABLE 5.

FILAMENT LAMPS SUITABLE AS BALLASTS FOR FLUORESCENT LAMPS ON D.C. SUPPLIES.

Supply Voltage	4 ft. 40W Fluorescent Lamp		5 ft. 80W Fluorescent Lamp	
	Single Lamp as ballast	Two Lamps in parallel as ballast: each—	Single Lamp as ballast	Two Lamps in parallel as ballast: each—
200	240V 150W	200V 60W	240V 300W	240V 150W
210	250V 150W	210V 60W	250V 300W	250V 150W
220	250V 150W	220V 60W	200V 200W	200V 100W
230	200V 100W	220V 60W	200V 200W	200V 100W
240	200V 100W	230V 60W	210V 200W	210V 100W
250	210V 100W	240V 60W	210V 200W	210V 100W

Power Factor with Resistive Ballast.

When either a wire-wound or filament lamp ballast is employed alone on an A.C. supply, the power factor of the combination is unity in the sense that the current is in phase with the voltage and there is no need to include a power factor correction capacitor. If a choke is included to assist in starting the fluorescent lamp, the power factor falls below unity by an amount dependent on the ratio of choke inductance to total ballast resistance. However, it is unlikely that the inductance required for starting will bring the power factor down to an extent which makes correction necessary.

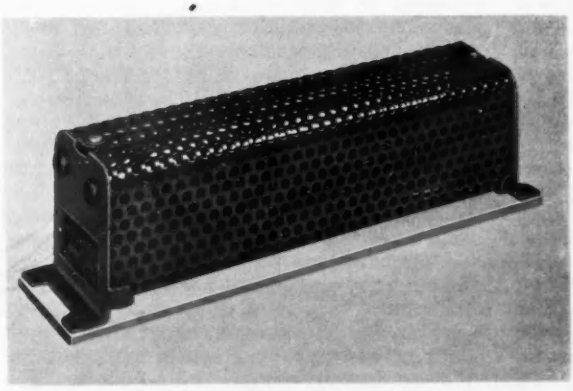

Fig. 7.—A ballast resistance suitable for use with an 80 watt lamp.

Starting with Resistive Ballast on A.C. Supplies.

The main attraction of a resistance ballast on A.C. is that it may avoid the necessity for the choke and power factor correction capacitor and thus achieve a reduction in the initial cost of the equipment. If a choke has to be included for starting purposes, although this need not be as costly as one performing the ballast function, it must increase the cost to some extent and is therefore an unwelcome addition. It is thus desirable to investigate under what circumstances the starting choke may be omitted.

The influence of lamp length on minimum starting voltage has already been mentioned and it is clear that the 8 ft. lamp cannot be considered in this connection on normal supply voltages. In the case of the 5 ft. lamp, experiments have shown that starting in the non-inductive switch-start circuit on supplies at the lower end of the 200/250 volt mains range is too unreliable to be considered, but on 240/250 volts starting without a choke may be considered as practical under favourable conditions, provided that the several " tries " which will often occur before stability is achieved can be accepted.

Chokeless starting is more feasible on A.C. than on a similar D.C. supply voltage because with the former the crest voltage available is $\sqrt{2}$ times the nominal r.m.s. value, and when the starter contacts open at or near an instant of maximum voltage this is available to initiate the discharge. The instant during the voltage cycle at which the starter contacts open is quite haphazard, but as they open repeatedly until the lamp strikes it is unlikely to take long before an opening occurs at a favourable instant.

Some improvement may be gained if an instant-start lamp is used with its starting strip earthed, and other methods for improving chokeless starting are known, but they involve the use of special lamps or additional gear.

With the 4 ft. or 3 ft. lamp the reliability of starting is probably adequate over the 220/250 volt mains range to satisfy those who are prepared to put up with some hesitation at starting to secure the saving in initial cost. Again, however, there is a marked difference in performance between the lower and the higher end of the voltage range, and it is difficult to recommend the chokeless switch-start circuit, therefore, without reservations.

While the saving in first cost which can be obtained by the use of chokeless A.C. ballasts is admittedly attractive, over a period of years the extra value of electricity used due to the heavy loss in the resistance may well exceed the initial saving. Owing to the higher current and lower lamp voltage, on A.C. the loss due to a resistance ballast is somewhat greater than the value shown for D.C. in Table 2.

PLAIN INDUCTIVE CONTROL.

Plain inductive control comes next to resistive control in order of simplicity on A.C. supplies, and its advantages have resulted in its being used far more extensively than any other method. The lamp current is limited by a choke coil whose reactance is large compared with its resistance. Thus when the starter opens the cathode pre-heating circuit, a surge voltage is developed and the lamp starts. Under operating conditions the ballast loss is only a fraction of the power expended in the fluorescent lamp, and the heat to be dissipated is small compared with that from a resistive control.

Essentially, a choke for the control of a fluorescent lamp consists of a coil of insulated wire wound on an iron core. The core is shaped so that the magnetic circuit is completed in the iron, but a small gap is normally left to control the magnetic characteristic, to reduce the current wave-form distortion which otherwise occurs due to saturation, and to obtain a choke of economical proportions.

To secure economy in the number of turns and in the core section necessary, the air gap must be small, but the smaller it is, the more critical is its effect on the characteristics of the choke. In some designs the final adjustment of characteristic during manufacture is carried out by altering the gap while in others the gap is fixed due to the design of the core stampings and the final adjustment in manufacture is carried out by altering the position of the winding on the core.

The design of a good choke is a complex matter. Primarily it must provide the optimum operating and starting conditions for the lamp when the supply is at nominal voltage and frequency. It must cater also for the variations in supply which may occur in service with the minimum of disturbance to the lamp. An acceptable balance must be achieved between the cost of materials used and the energy loss in the winding and core. The temperature rise under the worst conditions must be within the safe limit for the winding insulation and any other materials used in the construction. The characteristics must remain constant in spite of rough handling in transit, variations in the proximity of ferrous metal, and over long periods of service. The choke must be quiet in operation and must be capable of withstanding the worst conditions of ambient temperature, humidity and atmospheric pollution of either organic or inorganic form to which it may be subjected. Finally, its shape and overall dimensions must be acceptable and it should be free from restrictions as to the position and method of mounting.

It will be appreciated that to satisfy all these requirements is no easy matter, particularly when it is also necessary to keep the cost down to a competitive figure. Some examination of these requirements and their influence on current designs may be of interest.

ELECTRICAL CHARACTERISTICS.

The operating point or running setting of a choke is determined by the characteristics of the lamp and the supply voltage on which it is to operate. Since for any nominal supply voltage actual variation between + 6 per cent and — 8½ per cent is permitted at the terminals of the lighting fitting, and some spread in lamp characteristics must also be allowed for, it is evident that tolerances on choke setting must be made as narrow as possible to keep the spread of lamp operating current within bounds. This precludes the use of a simple untapped choke

over anything approaching the full 200/250 volt range of supplies, and in practice it has been found necessary to limit the nominal supply voltage coverage of a single choke to 10 volts in the 200/250 volt range. The objective running

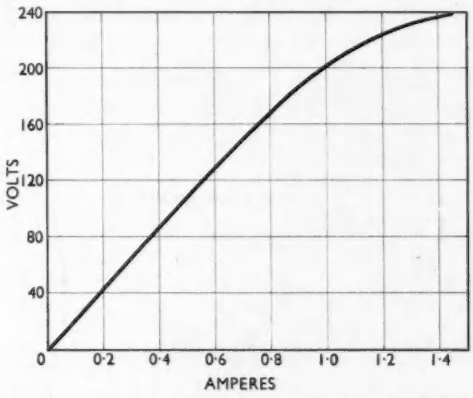

Fig. 8.—Typical volt/ampere characteristic for a 230/240 volt 80 watt choke.

setting of the choke for nominal lamp wattage with an average lamp is that which gives this wattage at a mean within the ten volt range. Thus for a 220/230 volt choke, the setting is correct for 225 volts. It is found possible by careful control in manufacture to keep the maximum variations in this setting within $\pm$ 1½ per cent of the objective voltage when passing nominal lamp current.

Initially, the supply range of 200/250 volts was covered by three chokes for 200/210, 220/230 and 240/250 volts, but when the proposed supply standardisation at 240 volts was announced it was clear that this choice of ranges, though the most economical in choke types, had a disadvantage. By far the largest number of supplies were (and still are) at 230 volts and where 220/230 volt chokes are used the conversion to the new standard of 240 volts involves changing the chokes. To avoid the necessity for this change, therefore, a 230/240 volt choke rating was introduced. In order to give a similar facility in the capacitive circuit (dealt with later) a 210/220 volt rating is also necessary, so that the normal ranges now covered by untapped chokes are 200/210, 210/220, 230/240 and 240/250 volts. This choice of ranges creates an ambiguity in the case of 210 and 240 volt supplies, and where there are no guiding factors it is prudent to adopt the higher rating on normal circuits, since this leaves a larger margin in hand to cater for periods of high ambient temperature or high voltage. If, however, it is known that the actual supply voltage is generally below nominal, then the lower choke rating may be more appropriate.

Tapped chokes have been made for fluorescent lamps, but they are necessarily more costly than untapped types and the achievement of setting accuracy on all taps is difficult. Mechanical difficulties in bringing out the tappings in some forms of choke also arise, and it is now generally agreed that tapless chokes with their economy in materials and in cost are preferable for use with fluorescent lamps.

Though not so critical as the setting for running conditions, a setting corresponding to cathode pre-heating conditions is also specified for chokes. This is sometimes referred to as the short circuit setting, because it involves a specified current when the choke is connected directly across a supply at the mean voltage mentioned above. The permissible tolerance in current for specified voltage in this case is $\pm$ 7 per cent because there is some latitude in the range of cathode heating conditions which give satisfactory lamp performance, and the employment of narrower limits would be liable to increase the cost of the choke materially while showing no advantage in performance.

Fig. 8 shows a typical characteristic for a choke. Starting from the origin, it will be seen that the voltage/current relationship is practically linear up to a little beyond the operating point, but at higher voltages the core begins to saturate and the curve bends. With full supply voltage across the choke the saturation is such that about 60 per cent more current flows than at the operating point, although the voltage is only some 30 per cent higher.

Thus, over the normal variations in operation, the choke control follows a roughly linear law, but good use is made of core saturation to permit an adequate value of cathode pre-heating current under starting conditions. Figs. 3 and 4[1] show the way in which the lamp current and wattage vary with varying supply voltage in a specific case using a choke whose characteristics are similar to those shown in fig. 8. It will be seen that up to the full 6 per cent permissible rise in supply voltage, the lamp current increase is roughly linear since choke saturation has not begun to have much effect. The rise in lamp wattage is appreciably less in proportion than that in current, owing principally to the accompanying fall in lamp voltage. Though not shown in fig. 4, the proportionate increase in light output is even smaller than that of the wattage because the luminous efficiency falls with increasing lamp

[1] See also fig. 13, p. 172.

watts. Thus a satisfactory measure of stability is achieved under excess voltage conditions, and the same is true for similar voltage variations in the downward direction. In comparison it may be noted that for similar supply variations the corresponding change in light output with tungsten filament lamps is about three times as great.

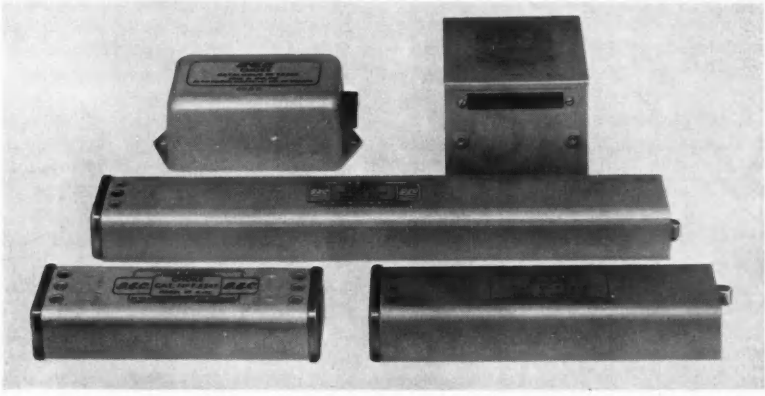

Fig. 9.—Various types of choke for fluorescent lamps. At the back are the old cubic tapless type (*right*) and the latest brick choke (*left*), while in front are long chokes for various lamps and supplies.

CHOKE LOSSES.

If other considerations such as size, shape and cost could be ignored, it would be possible to design a choke with extremely small losses, but in practice these factors are of great importance and appreciable choke losses must therefore be tolerated.

In practical designs, the larger proportion of the choke loss occurs in the windings, so a minimum number of turns and mean turn length coupled with a maximum gauge of wire are very desirable in securing minimum loss. Considerations of cost prohibit the use of anything other than normal commercial grades of iron in the core, and as the flux density at which the core can be operated is largely determined by the VA characteristic required, the minimising of total core weight is a major consideration in securing a low iron loss.

Thus it is found that a roughly cubic shape, with its economical use of both iron and copper, gives the lowest practical choke loss. The cubic 80 watt design illustrated in fig. 9 has a total loss under normal operating conditions of current and temperature of about 10 watts, and weighs 5·3 lbs. (core and coil only, 3·7 lbs.).

This cubic shape, in the case illustrated (fig. 9) measuring about 4 ins. in each dimension, restricts the design of lighting fittings which must provide space for its accommodation. It gives rise either to a " hump " above the main line of the fitting or to an elongation at the end, and there are many applications where neither of these is acceptable.

The long shaped choke, also illustrated, was introduced largely at the request of fittings designers so that the gear could be accommodated with the absolute minimum of disturbance to the slender line of the lamp and its associated reflector or diffuser. An 80 watt choke in this form measures only about $2\frac{1}{4}$ by $1\frac{1}{2}$ ins. in section, but in order to pack the necessary active material into this section, the magnetic circuit is elongated and the winding spread thinly over long formers with the result that many extra turns are required and an appreciably heavier weight of core is involved. The weight is 4·8 lbs. (core and coils only, 4·4 lbs.) and the loss is practically double that of the cubic design. Thus the very slim section is achieved only at some extra cost in material and considerable extra cost in power.

There are, of course, cases in which the elongated choke is the only shape which can be accommodated without the proportions of the fitting being impaired and this may justify a choke design in itself uneconomic. But much thought has been given to a compromise design which, while retaining much of the economy of the cubic choke, would nevertheless assume dimensions not inconsistent with the requirements of neat fittings.

The so-called " Brick " choke also illustrated in fig. 9 is an example of this compromise. It has a section about 3 ins. by $2\frac{1}{4}$ ins. in the

80 watt size and makes extremely efficient use of materials with a weight of 4·5 lbs. (core and coils only, 3·3 lbs.). The loss is only some 12 watts and there is therefore every reason to believe that this design will in future largely take the place of both the cubic and the long types. Only by concentrating bulk production into the smallest number of different types can economical manufacturing costs be secured.

Only the 80 watt choke has been referred to in dealing with the interdependence of losses and other design features, but somewhat similar considerations apply in the case of gear for other lamps. When the wattage concerned is lower, however, the long type gear proves not to be so different in loss and economics as is the case with the larger lamp. If economies can be effected by departing from the present elongated shape, they will certainly not be so striking as has been indicated in the 80 watt size. Table 6 gives the losses associated with chokes at present available. In making comparisons it must be remembered that these loss figures are for the chokes at normal operating temperature. Figures about 10-15 per cent lower occur when measured cold as is the practice of some manufacturers.

HEAT DISSIPATION AND TEMPERATURE RISE.

The ability of a choke to dissipate the heat corresponding to its energy loss without excessive temperature rise is a matter of prime importance. There is no technical difficulty in designing for a small temperature rise, but the resultant bulk and cost are high. For maximum economy without sacrificing reliability it is necessary to design for a temperature rise (under the worst service conditions to be catered for) which is just within the limit set by the insulation used. Designed thus, the choke will have a satisfactory thermal safety factor under normal operating conditions, but it may be necessary to specify limiting conditions of both current and ambient temperature. The range of service conditions encountered with a world-wide market and with the variety of lighting fittings which exist is very large. Consequently gear designed with the requirements of the normal highly competitive home market in mind is not always suitable for the extreme conditions encountered where the ambient temperature is high.

High ambient temperature may be due to external conditions or to the enclosed nature of the fitting or to a combination of both. Whatever the cause, the effect on the choke is magnified because not only is the actual operating temperature of the choke increased due to the extra ambient of its surroundings, but also due to the heavier current which it is called upon to carry. The latter follows from the temperature/current characteristic of the fluorescent lamp already described (page 162).

The dissipation of heat from the choke is dependent upon a variety of factors. Good thermal conduction from the winding and core

TABLE 6.

CHOKE LOSSES AND WINDING RESISTANCES.

Choke Type	Approximate Loss in Watts	Approximate Winding Resistance Ohms
80W Cubic Tapless	10	9
80W Long	20	16
80W Brick	12	9
40W Long (for 4 ft. lamp)	12	36
40W Long (for 2 ft. lamp on 100/130V)	10	8
30W Long	10	37
15/20W Long (200/250V)	12	40
20W Long (100/130V)	5	17
15W Long (100/130V)	5	18

NOTE.

The above losses refer to standard chokes for 50 cycle supplies when carrying the rated current for the appropriate lamp and at normal operating temperature (75 degs. C.). The D.C. resistances refer to a temperature of 15 degs. C.

to the case is dependent on a careful choice of filling compound, on the avoidance of air pockets in the filling, and upon securing the minimum thickness of compound between coils and case consistent with complete penetration. Even the painting of the external surface of the case is found to assist dissipation as compared with a bright metallic surface, although the colour of the paint has a negligible influence.

Where the choke is secured to metal which is in contact with free air, it can be of assistance in aiding heat dissipation, provided that the choke is in good thermal contact with this external metalwork. The adjacent surfaces are not usually altogether flat and it has been found in certain cases that improved conduction results from the use of a sheet metal shim clamped tightly between the two surfaces by the choke securing bolts.

Ventilation of the choke housing may aid heat dissipation, where adequate vents are provided both below and above to secure convection. Where the chokes are housed immediately above the lamps, however, convection cooling will be impaired if the air drawn in has already been warmed by the lamps.

Fig. 10 shows a typical current/temperature curve for a brick type choke, as measured by the change in winding resistance with the choke in the open at an ambient of 20 degs. C. A corresponding curve for rise in temperature of the case is also given. It will be seen that for the normal operating current, the internal temperature rise is about 40 degs. C. The upper limit of temperature for the enamelled wire and filling used is about 130 degs. C., so an adequate margin is given to cater for the high current and high ambient conditions which may be encountered in normal service.

Choke Noise.

Equipment involving magnetic material is always prone to generate a hum in the presence of an alternating magnetic field, and this is particularly the case when, as in the choke, there is an air gap in the magnetic path. This is partly due to the tendency of the field to draw the core faces together at the gap and partly due to the influence of the leakage field at the gap and elsewhere which will tend to vibrate the adjacent ferrous metal of the choke case or of the fitting. Magnetostriction also gives rise to some noise, but in chokes this is a minor and negligible effect.

Under certain conditions chokes can cause a really loud noise, but even a hum which is inaudible where there are other competing noises may be objectionable in really quiet surroundings, and it is therefore essential to ensure that chokes for fluorescent lamps which may be used in such conditions shall be as quiet as possible.

The first essential is that the laminations forming the core shall be clamped together very tightly and permanently, also that the gap shall be packed and cemented very solidly. In both the long and brick designs illustrated (fig. 9) the gap is in the middle of the core limb passing through the winding, where it is well spaced from the case and where the leakage field is reduced to a minimum. This part of the core is wedged very tightly by means of packing pieces which are driven into the tunnel after the core is assembled. The bitumen filling also plays

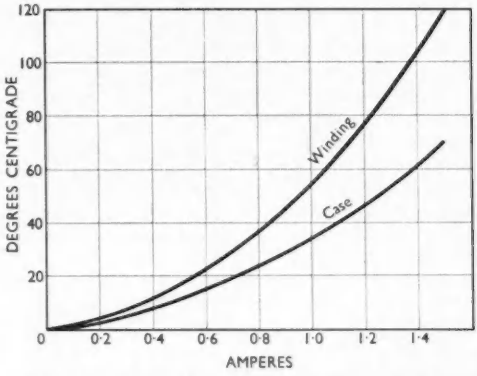

Fig. 10.—Current/temperature rise characteristic for 240/250 volt brick choke in free air. Somewhat smaller temperature rises occur with chokes of the same type for lower supply voltages.

a part in silencing the choke, particularly where it has good adhesion to both core and case. It not only holds the core tightly together, but also tends to prevent the steel case from vibrating. Non-ferrous cases would be relatively free from magnetic vibration, but they are not generally used because of their lack of magnetic screening effect. Were they used, there would be a tendency for the stray field to vibrate adjacent ferrous metal in the fitting, and this might alter the characteristics of the choke. The normal sheet steel choke case has that effect, of course, but this is allowed for in the initial setting adjustment.

By careful attention to these and other points, it has been found possible to keep the noise level of long chokes well below 15 phons, measured at a distance of 36 inches, and the brick design is even quieter.

Power Factor of Lamp and Choke.

Although, as already mentioned, the current and voltage of the fluorescent lamp are in phase,

the use of an inductive ballast which alone normally has a power factor of under 0·1, results in an overall power factor of about 0·5 lagging for the lamp and choke in combination (see fig. 11). To raise the power factor to an acceptable value, a suitable capacitor is normally connected across the supply to each lamp (see fig. 15). An alternative method of achieving a high overall power factor is to operate alternate lamps through ballasts which are capacitive in nature. Such an arrangement has two principal advantages. It gives an overall power factor which is very nearly unity, and it is economical in total capacitor cost.

THE CAPACITIVE BALLAST.

It is possible to operate a fluorescent lamp by using as its control impedance a capacitor only, but on normal supply frequencies this results in a very peaked lamp current wave-form which is destructive to the electrodes and results in an objectionable light output wave-form prone to give marked stroboscopic effects and flicker.

But when a capacitor is used in series with a choke, by careful selection of the value of each component it is possible to obtain a lamp current wave-form very similar to that with an inductive ballast and to achieve a power factor of between 0·5 and 0·6 leading. In combination with a second lamp operated through a choke only, this arrangement is known as the " T.L." or Twin Lamp Circuit. The circuit has been illustrated and described previously in this Journal[1] and here it is intended only to deal with the characteristics of the capacitive ballast.

In this type of control, the same range of chokes as for the inductive circuit is used, though not always the same voltage rating. One size of series capacitor serves for the full 200/250 volt range of supplies. This is chosen to give the correct lamp current at the mid-point of the voltage range (225 volts) when operating with a choke designed for correct inductive circuit operation at this voltage. In fig. 11, diagram A shows the vectors for lamp, choke and supply in this mid-point inductive case. Diagram B shows the capacitive combination for the same supply voltage. The circuit current and choke voltage drop are similar in magnitude to those in A, though their phase relation with the mains voltage is changed due to the introduction of the series capacitor. It will be noted that the voltage across the capacitor is roughly double that across the choke to preserve the correct voltage across the lamp, and that the current now leads the supply voltage vector by an angle similar in magnitude to the angle of lag in A.

TABLE 7.

CHOKES FOR USE IN CAPACITIVE CIRCUITS FOR VARIOUS SUPPLY VOLTAGES.

Actual Supply Voltage	Normal (inductive circuit) voltage rating of choke used in series with capacitor.
200/210	240/250
210/220	230/240
230/240	210/220
240/250	200/210

In diagram C, the supply voltage has been increased, and it is clear that to preserve the same circuit current and series capacitance, the choke voltage drop must be reduced, i.e. a choke intended for a *lower* voltage in the inductive circuit is necessary. Conversely, with a lower supply voltage the choke must be one designed for a higher inductive circuit voltage as in diagram D. Table 7 shows how this choke rating reversal in the capacitive circuit is applied with the four ratings now made. Previously, when a 220/230 voltage rating was usual, on

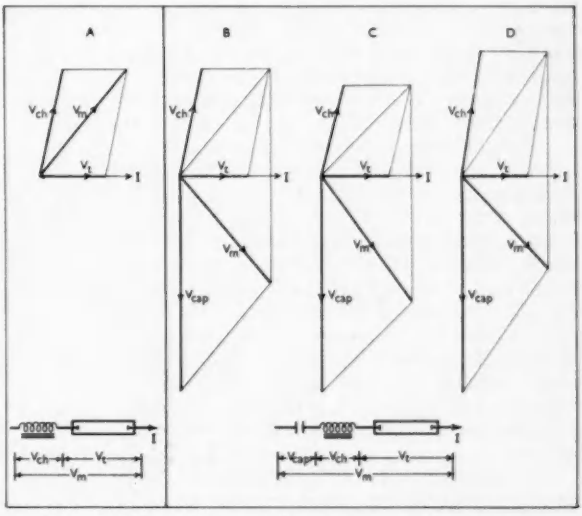

Fig. 11.—Vector diagrams for fluorescent lamp circuits. A—Inductive circuit on 220/230 volt. B, C and D—Capacitive circuit on 220/230, 240/250 and 200/210 volt respectively.

[1] Vol. XIII, No. 4, August, 1945.

these voltages the same choke was used for both inductive and capacitive circuits.

A typical characteristic for a capacitive ballast is shown in fig. 12. and the effect of supply voltage variations on lamp operation in the capacitive circuit is shown in fig. 13. From these

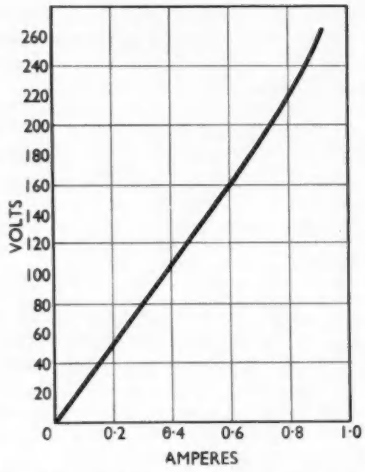

Fig. 12.—Typical volt/ampere characteristic for capacitive ballast used for 80 watt lamps on 230/240 volt supplies. (Compare with fig. 8.)

curves it is evident that the circuit provides more nearly stable lamp operation under mains variations than does the inductive circuit. This feature has two notable effects. In the capacitive circuit the lamp will remain alight under a considerably more severe voltage drop as compared with inductive control, and its light output varies less. Under starting conditions, however, owing to the more nearly constant current characteristic of the ballast, the current available to pre-heat the electrodes is little greater than the normal operating current.

To increase the starting current to a more normal value a separate compensating winding on the choke, connected in series with the starter contacts, has sometimes been used. Owing to the added complication, however, and since experience has shown no marked difference in lamp starting and performance between the inductive and uncompensated capacitive circuits, compensators are not normally used in this country.

Although capacitive circuits are insensitive to supply voltage variations they are more sensitive than inductive circuits to frequency changes, and where the frequency is likely to vary more than 3 per cent, as, for example, where the supply is from a small private plant, the capacitive circuit is not recommended.

Since a good series capacitor introduces a negligible loss into the circuit, the ballast loss in the capacitive circuit is sensibly the same as that given for the choke alone in Table 6. Table 8 shows details of capacitors for series operation.

Capacitive Operation of 8 ft. 125 watt Lamps.

An interesting example in which the high stability of the capacitive circuit plays a major part is that of the 8 ft. 125 watt lamp. With a lamp voltage of 170, operation in an inductive circuit on 200/250 volts mains would be unsatisfactory because there is insufficient difference between the two for good stability. Using the capacitive circuit, however, with an input voltage of 240 or 250, satisfactory operation is secured. The 7 mfd. capacitor with a 210/220 volt choke, as used with the 80 watt lamp on 230/240 volt mains, provides a satisfactory ballast impedance. The same components are used in this circuit on lower voltage supplies with a small step-up auto transformer, since stability of operation is not adequate with the 8 ft. lamp in the capacitive circuit on lower voltages. The whole circuit for 200/230 volts is shown in fig. 16. For 220/230 volt supplies one of the transformers made for instant-start circuits is utilised, while for 200/210 volts a special autotransformer in long gear form is available.

The overall power factor is a leading one of about 0·7 and although there is no similar lagging

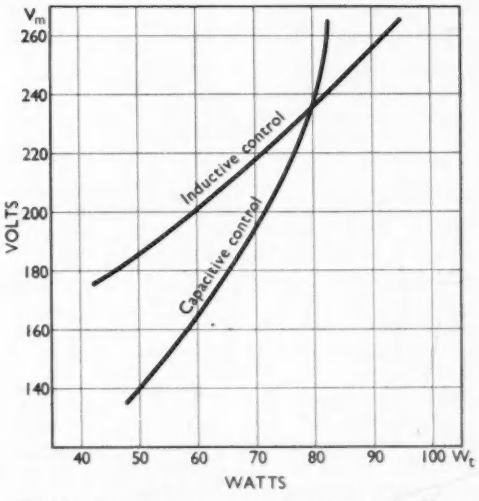

Fig. 13.—Typical current/watts characteristic for 80 watt lamp using capacitive control designed for 230/240 volt supplies. A corresponding curve for inductive control is given for comparison.

power factor circuit to balance out the reactive component, this capacitive circuit has been used alone in a considerable number of installations. It is believed that the Electricity Boards regard such capacitive loads favourably because they tend to raise the system power factor, which is invariably a lagging one.

POWER FACTOR CORRECTION.

It has already been pointed out that in the inductive circuit the power factor of the lamp and choke together is about 0·5, and where the twin-lamp arrangement for securing a high power factor is not employed, each lamp circuit normally includes a shunt capacitor across the supply terminals for power factor improvement.

The relationship between capacitance and corrected power factor in a typical case is shown in fig. 15. The corrected power factor obtained with a given size of capacitor varies slightly with the mains voltage and other variables, but it is usual to neglect such considerations and to use one size of capacitor for a given lamp throughout the voltage range. The capacitance chosen is such as to provide correction to about 0·85.

Close tolerances are unnecessary for these capacitors and, to avoid unnecessary cost, a wide tolerance, i.e. a total variation of 40 per cent, is generally adopted. As, however, a preponderance of under-value capacitors might result in an undesirably low overall power factor, G.E.C. capacitors for fluorescent lamps are made within tolerances of — 10 per cent and + 30 per cent on the nominal value. Thus the tendency in the aggregate is always towards the high side, and insufficient correction is practically impossible unless capacitors are omitted.

Both series and shunt types are composed of aluminium foil and best quality capacitor tissue, vacuum impregnated with petroleum jelly and hermetically sealed in their cases. Safety discharge resistances are fitted internally across the terminals, the value of the leak being about

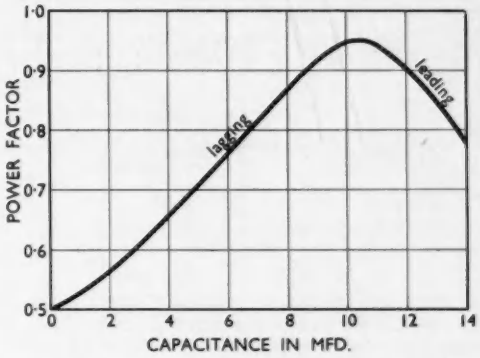

Fig. 15.—Typical relationship between shunt capacitance and corrected power factor for an 80 watt lamp circuit on 230/240 volt supply.

0·47 megohm. These leaks are of sufficiently high resistance to absorb a negligibly small power, but they ensure that when the circuit is switched off any charge remaining in the capacitor is rapidly drained away thus avoiding the danger of subsequent shock.

Being connected straight across the mains, and frequently situated in an enclosed channel where the temperature may be raised by the adjacent choke and by the lamp itself, capacitors must have a liberal safety factor to ensure

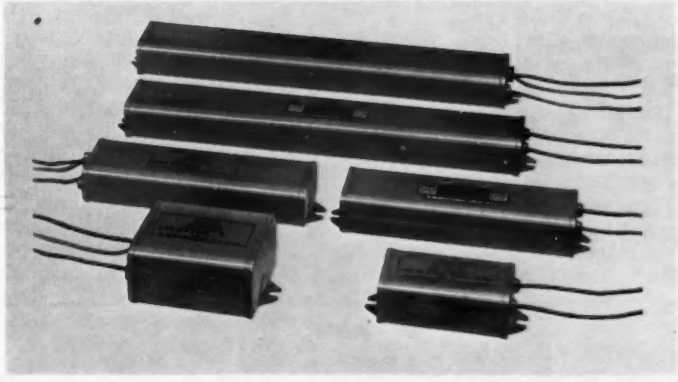

Fig. 14.—Capacitors for power factor correction and capacitive operation of fluorescent lamps. Those with three leads are for capacitive instant-start circuits.

reliability over long periods. This is achieved by careful manufacture and design, and by the use of high quality dielectric tissue and petroleum jelly. In types designed to operate at up to 250 volts A.C. two thicknesses of tissue are used between foils, while in the series types where

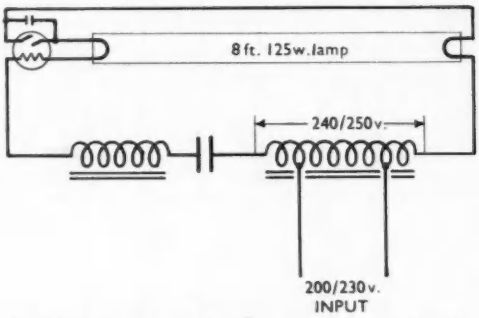

Fig. 16.—Capacitive control circuit for 8 ft. 125 watt lamp. The step-up transformer is omitted on 240/250 volt supplies.

the working voltage is of the order of 400, three or four thicknesses of tissue are employed. Thus, should there be an electrically weak spot in one tissue, this is covered by at least one sound layer.

Life tests extending over long periods show that G.E.C. capacitors are at present capable of withstanding a temperature of up to 70 degs. C. continuously, and research is proceeding with a view to achieving reliability at still higher ambients, but it is generally accepted that capacitor life varies inversely with temperature and it is therefore always desirable to locate them in as cool a position as possible. Since there is virtually no power loss in capacitors of the types used in fluorescent lamp circuits, they generate a negligible amount of heat in themselves and are best spaced away from metal work which might otherwise transfer heat to them by conduction.

Where capacitors are operated at high temperatures it is essential to provide a good seal against leakage of the filling where the connecting leads emerge through the bushings. In the type most commonly used, the bushing is made in bakelite with a metal ring and tube moulded in. The projecting ring is soldered into the case to fix the bushing in position, and where the lead passes through the central tube it is bared and solder is run in to close up the whole tube solid. In another type the bushing is of a synthetic rubber pressed into the hole in the case and fitted with a central lead tube flanged at the inner end and sealed with solder as in the case of the bakelite bush.

TABLE 8.

CAPACITORS FOR SERIES OPERATION WITH FLUORESCENT LAMPS ON 50 CYCLE SUPPLIES.

LAMP		SUPPLY VOLTAGE	CAPACITOR		Approximate Working Voltage
Watts	Length ins.		Value mfd.	Tolerance	
15	18	100/130	5	± 5 per cent	190
20	24	„	6·5	„	170
40	24	„	15	„	175
15	18	200/250	2·7	„	350
20	24	„	2·7	„	410
30	36	„	2·7	„	400
40	48	„	3·5	„	370
80	60	„	7	„	385

NOTE.

The above data refer to lamps used singly in all cases. Where two short lamps are used in series, the data given for the single lamp of the total wattage of the two are applicable.

The working voltages refer to simple series circuits during normal operation. Higher voltages may occur during starting, particularly where compensation is included.

INSTANT-START GEAR.

Although the starter switch is still the simplest and most economical device for starting a fluorescent lamp it has not an indefinite life, it does not give immediate starting, and it may complicate the location of a faulty component in the circuit of a fluorescent lamp. Instant-start circuits in which the only expendable item is the lamp itself are therefore gaining considerable popularity, both in cases where switching is frequent and in others where it is desired to reduce and simplify maintenance.

As stated in the initial section, when an earthed instant-start lamp is used and the cathodes are raised to a suitable temperature, the voltage between the electrodes necessary to start the lamp is within the range of normal supply voltages for lamps up to 5 ft. in length. The starting transformer is a unit designed, in conjunction with a choke, to give the requisite cathode pre-heating current and to give a small voltage step-up where this is necessary. To ensure reliable starting, after the cathodes are heated, in the case of the 5 ft. lamp about 220 volts must be applied, while with the 4 ft. and 3 ft. lamps about 200 volts are adequate. Both values include a margin of safety to allow for adverse conditions of voltage and atmosphere.

INDUCTIVE CIRCUIT GEAR.

The circuits used are shown in fig. 17. For 200/210 volt supplies, the 80 watt starting transformer is somewhat larger than for the higher mains voltages, because of the step-up ratio involved. The windings providing the cathode heating current are designed to give 14 volts each under open circuit conditions, and to pass about 1·3 amp. for 80 watt lamps under pre-heating conditions. With this current flowing, the cathodes reach emission temperature, the local cathode discharge starts, and the main discharge is initiated ; the whole operation being completed within a fraction of a second.

During starting, the transformer primary takes only about 0·1 amp. ; the voltage drop in the choke is therefore small, and practically the full supply voltage appears across the transformer primary. Once the lamp has started, the choke takes control and the voltage across the transformer is equal to the lamp voltage. Thus the voltage across each cathode is correspondingly reduced and only a small current continues to flow round each cathode heating circuit. The maintenance of cathode temperature is principally due to the discharge.

It will be seen from fig. 17 that in the 200 to 230 volt cases the transformers are connected with their secondaries additive while on 240/250 volt mains they are connected subtractively. Thus in the former the voltage applied to start the lamp is greater than that across the primary winding, while in the latter there is no step-up, and the ratio is reduced, thus avoiding overheating the cathodes.

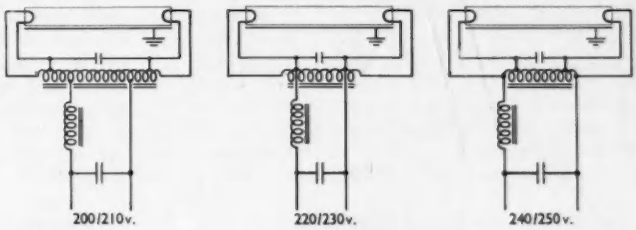

Fig. 17.—Instant-start circuits using inductive control with separate choke and starting transformer.

The starting transformer designed for use with 80-watt lamps on 220/250 volts may be used with 3 ft. 30 watt or 4 ft. 40 watt lamps on 200/230 volt supplies. The cathodes of these smaller lamps require much the same cathode pre-heating voltage, although owing to their higher resistance they take less current. On 240 and 250 volt supplies there is a tendency for the cathode heating current to be high. The 80 watt starting transformer is, of course, larger than necessary for the lower wattage lamps and a smaller transformer designed specifically for the 30 watt and 40 watt lamps will become available in due course.

One form of this which is under development and may well prove popular owing to its economy in first cost, is an open type starting transformer designed to cater for two 4 ft. 40 watt lamps. Since the ballast impedances for two lamps cannot be connected in parallel, the primary of the common starting transformer is connected directly across the supply. A somewhat sub-normal cathode pre-heating current is provided to avoid overheating when the lamp has started, and the arrangement may be used with filament lamps as ballast in order to reduce the first cost still further. The data for 40 watt lamps given in Table 4 refers to this arrangement.

Another type of inductive circuit starting transformer which is already available is that for operating two 24 in. 40 watt lamps in series. The circuit for this is shown in fig. 18. It will be seen that the arrangement is similar to that

for the single 80 watt lamp, but with an additional isolated winding which provides cathode heating current for the two intermediate cathodes connected in series.

Due to the insertion of a starting transformer between the choke and the lamp, the choke is

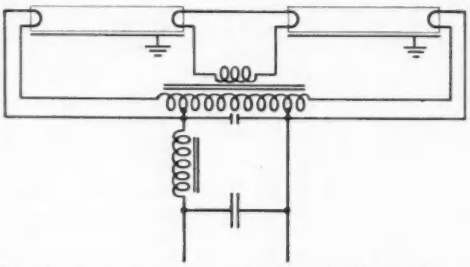

Fig. 18.—Instant-start circuit for two 2 ft. 40 watt lamps operated in series.

called upon to carry a larger current than that taken by the lamp. This is due in part to the transformer magnetising and residual cathode heating currents, but more especially to the voltage step-up where the cathode heating windings are connected additively. In the case of the transformer for 200/210 volt supplies where the step-up is greatest, the current through the choke is about 1·1 amp. under normal conditions. It is essential here to use a choke specially designed for the purpose, partly due to this high current and partly because an impedance lower than that of the normal 200/210 volt choke is required. In the other cases, normal chokes may be used as the current is within their capacity, but the lamp is operated at a few watts below its nominal rating.

The starting transformer magnetisation loss and the residual cathode heating involve an expenditure of power which is roughly similar to the amount by which the lamp wattage is reduced and ranges from about 2 watts on 250 volt mains to 10 watts on 200 volts. Thus the total power taken from the mains using this "long" instant-start gear remains roughly the same as in the simple choke control switch-start circuit. Shortly it is intended to introduce choke/transformer units in one case and these are designed to operate the lamp at full wattage. One of these composite units is illustrated in fig. 20.

Capacitive Instant-Start Gear.

A starting transformer similar to that used in the inductive circuit, though slightly different in characteristics, can be used in the capacitive instant-start circuit. But since the series capacitor prevents the passage of any asymmetrical component in the current from the mains, if the fluorescent lamp passes an asymmetric current, the D.C. component must pass through the starting transformer. Normally the lamp current is symmetrical, or has only a negligible D.C. component, but at the end of life it is not uncommon for one cathode to lose most of its emissive coating, while the other remains fully emissive. In such circumstances the lamp acts as a partial rectifier, there is a considerable asymmetric component in the current passing and the light from the lamp shows a pronounced flicker throughout the length of the tube. In the 80 watt case the mean value of the D.C. component may be of the order of a $\frac{1}{2}$ amp. and this being far in excess of the current for which the main winding of the starting transformer is designed, severe overheating and possibly failure occurs unless the lamp is taken out of service quickly.

To avoid this effect a circuit has been devised by the G.E.C. Research Laboratories which prevents any asymmetric current passing through the starting transformer. This involves isolating one cathode heating winding from the primary and connecting the free end of the latter to the centre point of a double series capacitor as shown in fig. 19. Thus the voltage applied to the primary of the transformer is not greatly changed, though to preserve the same total series capacitance in the control circuit each half must have double the capacitance. As the total voltage is divided, however, each half of the capacitor is called upon to withstand only about half the

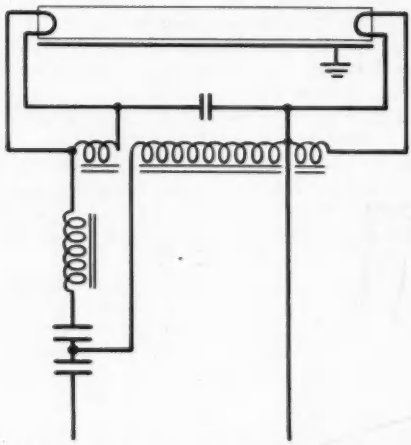

Fig. 19.—Instant-start circuit using capacitive control with provision for preventing asymmetric current in the transformer primary.

voltage and the overall size of the capacitor unit remains the same as for the single series capacitor.

The capacitive instant-start circuit exhibits similar characteristics in respect of stability and ability to hold the lamp alight down to a lower value of mains voltage than the inductive circuit as have already been described for the switch-start circuit. Since under low voltage conditions in both instant-start circuits the cathodes are assisted in maintaining an emissive temperature by the auxiliary cathode heating circuits, both are capable of maintaining the lamp alight down to appreciably lower supply voltages than in the corresponding switch-start circuits. As the lamp current falls, the lamp voltage and hence the starting transformer primary voltage rises, giving increased cathode heating current.

SUPPLY FREQUENCIES OTHER THAN 50 CYCLES.

While all the gear described and illustrated is intended for operation on 50 cycle supplies, it is sometimes possible to use it for the adjacent supply frequencies 40 and 60 cycles by choosing a 50 cycle voltage rating of choke which is above or below the actual 40 or 60 cycle supply voltage respectively. Similarly, a frequency of 25 cycles may be covered by using two 50 cycle chokes in series, and 100 cycles by means of two in parallel. The higher the frequency the smaller can be the gear, however, and it is generally uneconomical to use 50 cycle gear as compared with gear specially designed for the other frequency unless the quantity required is too small to make the provision of special gear worth while.

Where much higher frequencies are involved, extremely small control gear can be designed, and this miniaturisation has been most effective in the production of compact control gear for use on trains and road transport and of ultra light-weight gear for aircraft lighting. Special powder core chokes in toroid form have been developed by the G.E.C. for all these high frequency applications, and they possess two outstanding advantages over chokes of the normal laminated core construction in that they have very low losses and are completely silent in operation.

Fig. 20.—Starting transformers for 80 watt lamps. The longer of the small section units is for 200/210 volt supplies, while the brick-shaped unit is a composite choke/starting transformer.

CONCLUSION.

The reader may have formed the impression that control gear for fluorescent lamps is becoming more and more complicated with the development of new circuits and the introduction of new features. But if this is the case, it must equally be realised that the purpose of these complications in gear and circuits is to render better service to the user, and to eliminate or improve features which have given trouble in the past.

Remote Supervisory Control

By R. W. FIELD.

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Remote supervisory control is finding an ever-widening field of application. It is readily adaptable and enables the particular requirements of an Administration to be fulfilled in every respect. In this article mention is made of typical facilities available, and the general principles of operation are explained. An account is given of the equipment employed and forms of signalling are discussed. Four types of system are outlined, and the article ends with a description of the various methods of remote metering.

CENTRALISATION OF CONTROL.

IN any undertaking comprising plant situated at a number of different points such as, for example, electricity supply networks, traction systems or pumping plants, centralisation of control is essential if the highest degree of co-ordination is to be maintained between all points. This applies equally to small and large undertakings, and the use of a modern system of communication and remote supervisory control enables administration to be placed on the most efficient and economic basis.

FACILITIES.

As a result of experience of the wide variety of conditions and requirements to be fulfilled, a range of systems has been developed by the G.E.C. to satisfy practically any given combination of services to be provided and type of signalling channel over which the various signals are to be transmitted.

The services for which provision is made are :

(1) Supervisory control and indication.
(2) Telemetering.
(3) Telephony.
(4) Telegraphy by teleprinter.

The types of channel over which signals can be transmitted to give the facilities are :

(1) Rented circuits.
(2) Private aerial lines.
(3) Private cable.
(4) Power line carrier.
(5) V.H.F. radio link.

It is technically possible to provide any of the services over any of the signalling channels, but practical or economic considerations may affect the choice of signalling channel for certain services.

METHODS OF LINKING SUBSTATIONS TO CONTROL.

Typical methods of linking substations to the control station by any one, or a combination, of the types of signalling channels listed above are shown in figs. 1, 2, 3 and 4.

In fig. 1, the control station is situated centrally and the signalling channels radiate from it to the outlying substations.

In fig. 2, the substations are linked in tandem to the control station by a common signalling channel. This tandem arrangement is particularly applicable to traction systems, and to distribution systems where the relative positions of the control station and substations are such that they can be more conveniently or economically linked by a common signalling channel than by individual channels between the control station and each substation.

In fig. 3, signalling channels radiate from a major substation to a number of surrounding substations and to the control station. The major station becomes what is termed a group centre, all signals between the control station and the minor substations being passed or relayed through it.

In actual practice a combination of two or all of these arrangements is sometimes found, a typical example being given in fig. 4.

As a general rule, the complexity of the

terminal equipment is inversely proportional to the number of pilot wires provided.

The descriptions of the range of systems given in the following pages are intended to assist Administrations in the choice of the system best fitted to cover their conditions and the facilities required. Economy and expediency must always be considered so as to ensure that the conditions are fulfilled in the best way.

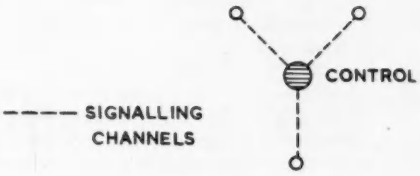


Fig. 1.—Radial connection.

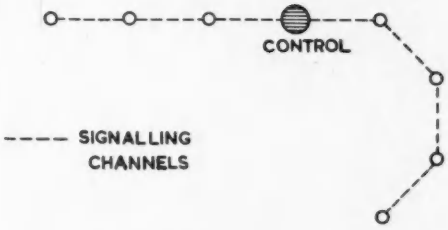


Fig. 2.—Tandem connection.

Supervisory Control Facilities.

Any plant which can be arranged so as to be electrically operated can be remotely controlled. The position or condition of plant can be remotely indicated provided suitable means of detection are available or can be fitted. Typical facilities are as follows :—

(1) Open and close circuit breakers.
(2) Change tappings of transformers and boosters.
(3) Synchronise supplies.
(4) Switch rectifiers on and off.
(5) Start and stop any form of control motor.
(6) Control hydraulic plant, such as sluice valves.
(7) Indicate the position of any of the items listed above.
(8) Read amps., volts, kW, kVA, power factor, water pressure and flow, gas pressure and flow, and any other variable quantity.

Principles of Supervisory Control Operation.

The function of any system of supervisory control is to enable a number of items of equipment to be controlled and indicated at a remote point over one or a limited number of channels. Selective supervisory control equipment achieves this object by enabling any item of substation switchgear to be associated, by way of the common signalling channel, with the appropriate control keys and position indicator at the control station.

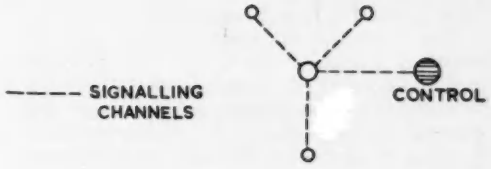


Fig. 3.—Group centre connection.

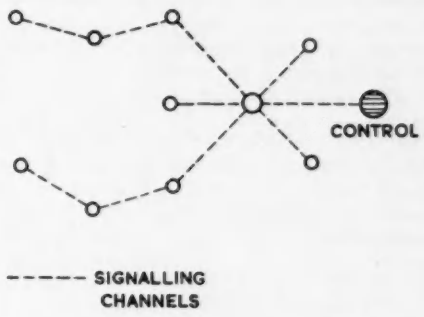


Fig. 4.—Typical combination of tandem and group centre connections.

Fig. 5 shows in diagrammatic form the application of a remote supervisory control system to an electricity supply undertaking, only one small substation being shown for simplicity. At the control station is situated a control panel on which appears a mimic diagram representing the whole undertaking. Circuit breakers are represented by discrepancy keys of the type described in the section " Switchgear Controlled and Indicated," and transformer tap-changing gear by a lever key and indicator. These are so positioned in the diagram as to be associated at a glance with their corresponding plant at the substation. In respect of the sub-

station shown it must be possible (*a*) to open, close and indicate the position of the H.T. circuit breaker, (*b*) to open, close and indicate the position of the L.T. circuit breaker, (*c*) to change and indicate the transformer tapping, and (*d*) to read current and voltage. The application of supervisory control equipment enables these facilities to be provided over a single channel. An idea of the number of pilot wires that would be required in this instance if supervisory control equipment were not employed is given by the number of connections which converge on the selective apparatus in fig. 5.

The process of connecting together, over the signalling channel, a particular item of switchgear and its associated control key and position indicator is termed *selection*. This process will be better understood if the procedure necessary to effect a particular operation is considered. Consider that the H.T. circuit breaker is open (as shown); the handle of the corresponding key will be across the diagram line representing the H.T. feeder, and the lamp within the handle will not be lit. If it is now required to close the H.T. breaker, the operations performed and the resulting sequence of events are as follows:

(1) The H.T. breaker key is turned in a clockwise direction to the *close operate* (*CO*) position.

(2) The lamp in the handle flashes to indicate that the position of the handle is not in agreement with the actual position of the breaker, while the supervisory apparatus carries out the selection operation necessary to cause the operated control key to be connected via the switching apparatus and the signalling channel to the associated breaker at the substation, the cycle of operations at the control station being maintained in step with a similar cycle of operations at the substation by signals transmitted over the signalling channel.

(3) The cycle of operations involved in selection is automatically checked stage by stage, and indication of its successful completion is given by a change in the character of the flashing of the lamp in the handle.

(4) On receipt of the *selection complete* signal the common *close* control push button is operated to cause signals to be transmitted from the control station to the substation to operate the *close* contactor.

(5) When the breaker closes, its auxiliary contacts cause signals to be transmitted back to the control station to cause the continuous lighting of the lamp in the handle.

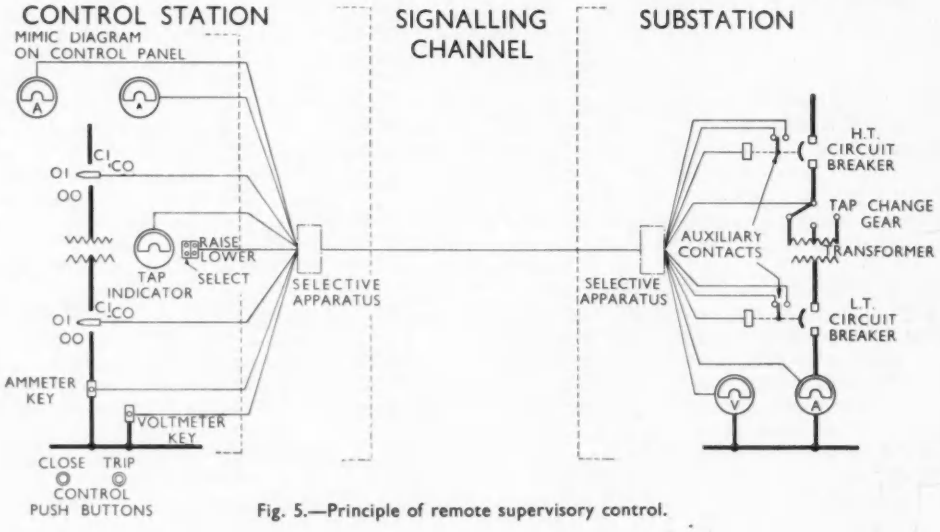


Fig. 5.—Principle of remote supervisory control.

A similar procedure will enable any other circuit breaker to be operated, while by means of two keys designated respectively *raise* and *lower*, the transformer tapping can be changed.

Meter readings may be obtained, either continuously or on demand, by throwing appropriate keys.

In the event of a circuit breaker being manually operated by the substation attendant or automatically tripped as a result of a fault condition, the supervisory control apparatus selects the affected plant and causes it to be connected via the switching apparatus and the signalling channel to the associated control panel indicator, which flashes to indicate that its position is not in agreement with that of the actual breaker. An audible alarm is also given. When the control key is turned to correspond with the new position of the circuit breaker, flashing ceases and the audible alarm is silenced. Manual or automatic operation of the transformer tap-changing mechanism also results in action by the supervisory control equipment to cause the control panel indicator to be brought into alignment with the new tap position.

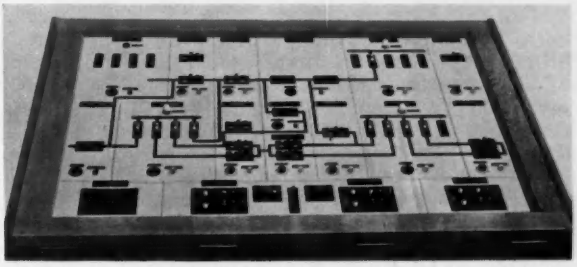


Fig. 7.—Control desk of the Waitemata Electric Power Board, New Zealand.

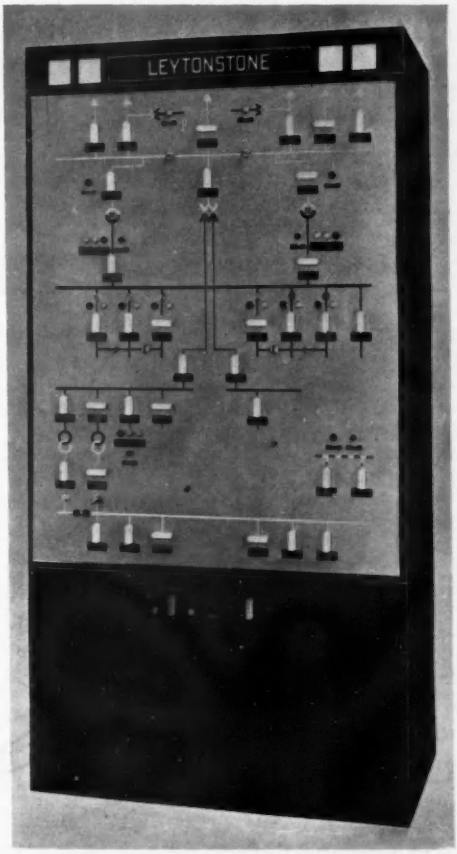


Fig. 6.—Control cubicle on the North East London extension of the London Transport Executive.

It is, of course, imperative to ensure that a control operation should never be directed to an item of equipment other than that intended, or for a change in the position of an item of substation switchgear to be recorded on any indicator other than that with which it is associated. All the G.E.C. systems have been designed so as to ensure that such mal-operation is virtually impossible, special circuit arrangements being made to check the correct functioning of the control station and substation selection equipment at each stage of the cycle of operations. Any failure results in the selection equipment being released and the lighting of a *fault* lamp on the control panel.

EQUIPMENT AND APPARATUS.

A feature of the G.E.C. systems is the small number of types of components required to cover a wide range of facilities. All components are reasonably small, are readily accessible and are compactly mounted in cabinets or cubicles, which can be accommodated in a small space. The apparatus employed falls under two main headings : (*a*) control panel and control room equipment, and (*b*) selective apparatus.

Control Panel.

The control panel is always constructed to meet the specific requirements of the customer. It can form the face of a vertical cubicle as illustrated in fig. 6, or it can form the sloping top of a desk as illustrated in fig. 7. Where a number of substations is controlled from one control room or load dispatch office the control panels can be mounted side by side to form a continuous suite arranged either in a straight line or in an arc as illustrated in fig. 8. The

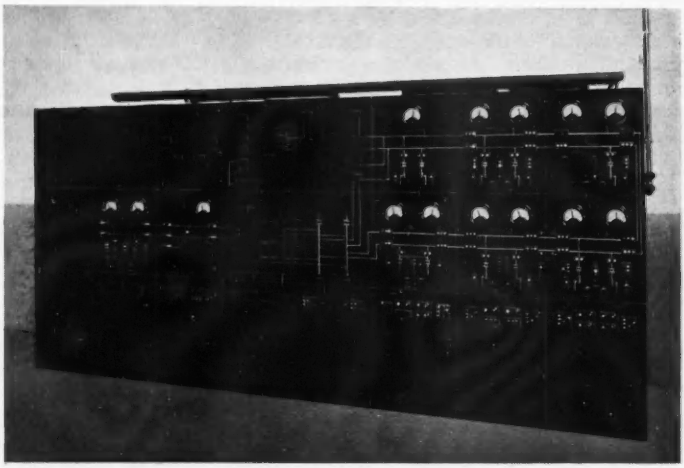
vertical cubicles are constructed of steel. The desks can be constructed either of wood or steel as required. The actual control panel is usually of sheet steel, but slate or other material can be used if required, and the finish can be in any desired colour. Painted lines or coloured strip form the mimic diagram.

Switchgear Controlled and Indicated.

The two most common control panel arrangements for the control and indication of a circuit breaker are shown in figs. 9 and 10. That shown in fig. 9 consists of a lever type select key, with which is associated red and green position indication lamps and a *selection check* monitor lamp.[1] The other, shown in fig. 10, is a discrepancy key, which enables the usual red and green lamps to be dispensed with, since its handle forms a part of the mimic diagram and thus provides a continuous indication of the condition of the associated circuit breaker. This key has five positions, and a lamp is housed within the moulded translucent handle, which can be easily removed to facilitate the replacement of the lamp.

Fig. 11 indicates diagrammatically the usual arrangement. When the handle is in agreement with the condition of the associated circuit breaker the lamp is not lit and when the handle is *not* in agreement the lamp flashes. If the circuit breaker is to be closed, the handle is rotated in a clockwise direction to the *close operate* position. The key is then not in agreement with the condition of the associated circuit

[1] The function of the monitor lamp is to indicate the completion of a selection operation initiated by the throwing of a *select* key.



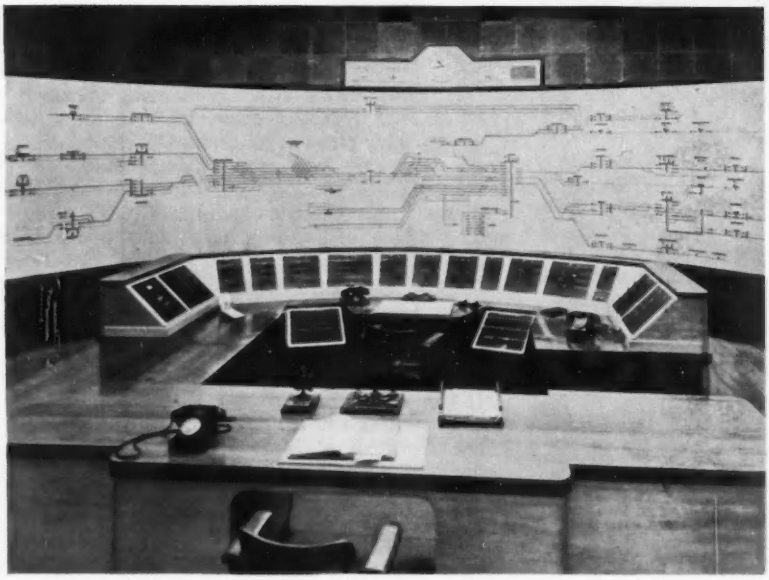


Fig. 8.—Suites of control panels (*above*) at Grassmoor substation, Derbyshire, and (*left*) the Melbourne control office of the Victoria State Railways.

breaker and consequently the lamp flashes and continues to flash until an indication signal is automatically returned to indicate that the circuit breaker has closed, when the flashing changes to a steady glow. The handle is then returned to the *close indicate* position, and, provided that the circuit breaker remains closed, the lamp in

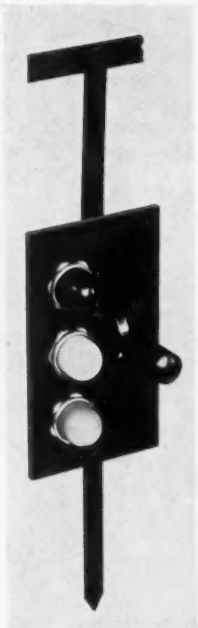


Fig. 9.—Lever-type select and indication key.

the handle is extinguished. When the circuit breaker is to be opened, the handle is turned in an anti-clockwise direction to the *open control* position, the sequence of events being similar to that described above. When flashing occurs in both the *open indicate* and *close indicate* positions, the handle is turned to the fault position. This condition might occur as a result of the circuit breaker being racked out from the busbars, or of failure of the auxiliary contacts. As this control key handle is of small dimensions, approximately 2 in. long, a mimic diagram control panel can be arranged in a very restricted space while still retaining an extremely clear diagram layout.

Switchgear Indicated but not Controlled.

The three most common methods of indicating the position of switchgear, such as circuit breakers, isolators and switches when their remote control is not required, are shown in fig. 12.

That shown in fig. 12a consists of red and green lamps; that shown in fig. 12b consists of a hand-set link with which is associated a discrepancy lamp. When the position of the link is in agreement with the item of switchgear it represents, the associated discrepancy lamp is not lit, but if it is out of agreement the lamp flashes.

The third method, shown in fig. 12c, is the discrepancy key. The same type as that already described for control and indication can be employed, the key then having only three positions instead of five. Alternatively, the smaller discrepancy key can be employed. This has only two positions, one indicating that the switch is closed and the other that the switch is open. In this key the lamp is housed within the hollow spindle which carries the cams for operating the contact springs. The indicating knob, which can easily be withdrawn to facilitate a change of lamp, consists of a chromium-plated metal ring, to which is fixed an aluminium bar and a moulded glass disc. The bar forms a handle and the glass disc covers the lamp. The bar is coloured to match the diagram line in which the key is fitted and conveniently forms a handle for rotating the knob. As with the large discrepancy key, when the position of the

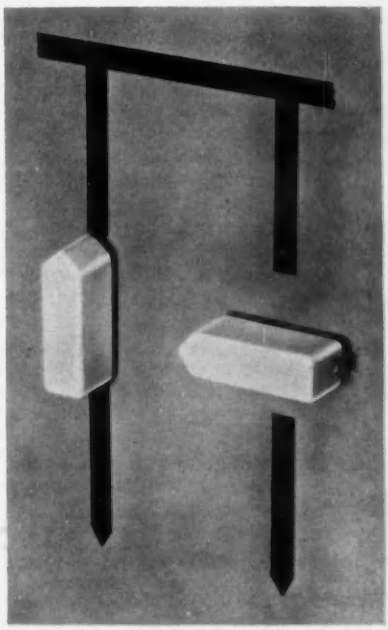


Fig. 10.—Discrepancy type select and indication key.

key is in agreement with the item of equipment it represents, the lamp is not lit and when it is *not* in agreement the lamp flashes. The knob is shaped to fit into an asymmetrical guide to ensure that it can be inserted only in the correct position.

Transformer Tap Indication.

There are two types of transformer tap indicator. One consists of a milliammeter with a scale divided into the same number of segments as there are tap positions on the transformer it is indicating. Arrangements are made in the associated circuit to deflect the meter pointer so that it is in agreement with the position of the transformer tap arm.

The other type of tap indicator comprises a group of telephone switchboard-type lamps, one for each tap position, mounted behind a translucent face plate on which are engraved the tap position numbers. The associated circuit is arranged to light the lamp behind the number corresponding to the tap on which the transformer tap arm is resting.

Indication of Alarms.

Alarms such as *main protection, back-up protection, over temperature, Buchholz*, and *busbar protection* can be indicated by a lamp fitted with a distinctively coloured cap and mounted adjacent to the relevant symbol in the mimic diagram. Alternatively, an alarm annunciator panel can be provided at the top of the control panel, the alarm lamps being positioned directly above the mimic diagram symbols with which they are associated and covered by a face plate of translucent material, suitably engraved, in front of each lamp.

Indicating Meters.

Meters for the indication of amps., volts, kW, kVA, power factor, water pressure or any other variable quantity can be of any size or design to suit the customer's requirements and to fit in with the general control panel arrangements.

Recorders.

Instruments for recording any variable quantity can be supplied.

CONTROL ENGINEER'S DESK.

When a remote control system is sufficiently extensive to warrant the full-time attendance of a control engineer, an engineer's desk is usually installed to carry all the necessary control keys, telephone switching arrangements and meters.

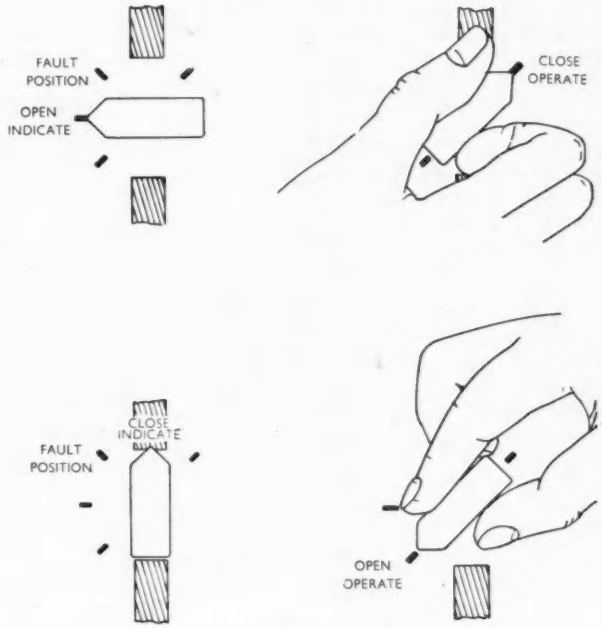


Fig. 11.—Positions of a discrepancy key.

Control engineers' desks are designed to meet the specific requirements of the customer and to harmonise with general control room arrangements. They are usually constructed of oak, walnut, mahogany or teak. The smaller remote control installations may not warrant the provision of a desk ; the necessary services can then usually be accommodated on a turret which can be mounted on the rear of a table.

Teleprinters and Speech Recorders.

When the efficient operation of a remote control system requires the transmission of printed messages or the recording of telephone conversations, teleprinters and speech recorders are provided and are usually mounted at the side of, or behind, the control desk so that they can be easily manipulated by the control engineer.

SELECTIVE AND CONTROL APPARATUS.

Depending upon the size of the remote control

installation and upon the operating requirements of the system, the selective and control apparatus at the control station is housed either within the control cubicle or desk or in a dust-proof sheet steel cabinet which can be located at a distance from the control panel. In the larger installations, the selective and control apparatus is almost invariably mounted in cabinets which are usually housed in an apparatus room adjacent to the control room. This system possesses the advantage that maintenance work and routine tests can be carried out with the least inconvenience to the control room personnel. The removal from the control room of all apparatus creating noise, however slight, is another advantage.

The apparatus at the substation is housed in similar cabinets to those used at the control station. One type of cabinet is illustrated in fig. 13.

The two principal components are the relay and the uniselector, identical with those used in automatic telephony, and standardised by the British Post Office. The outstanding performance and reliability of these components have been generally recognised and they can now be found performing a wide variety of functions in all branches of the electrical industry.

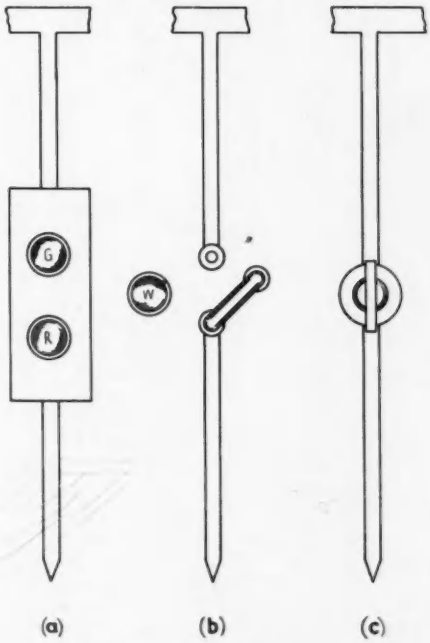


Fig. 12.—Three methods of indicating switchgear position.

TYPES OF SYSTEMS.

The two most important factors governing the type of system employed are :

(*a*) The type of signalling channel available, which determines the method of signalling to be used ;

(*b*) the number of control and indication facilities required.

D.C. SIGNALLING.

The simplest method of passing signals between two stations is by direct current impulses over a physical circuit consisting of two or more wires, either overhead or underground. In such systems a relay operating at one end of the circuit connects a D.C. supply to the circuit and thus operates a relay at the distant station.

Where there is a possibility of high voltages being induced in the pilot circuit, because of, for instance, its close proximity to high tension power conductors, precautions are taken to prevent the voltages from spreading through the supervisory equipment and causing damage through insulation breakdown and possible injury to personnel.

Where circuits are rented from a separate authority and terminated in E.H.T. substations, a usual stipulation is that voltages produced in the substation must be prevented from reaching the lines.

For the above two reasons high-voltage insulation is provided between the terminal equipment and the communication circuit. In a D.C. impulsing system this insulation may take the form of line signalling relays with large physical and electrical separation between their operating coils and contact assemblies. Test voltages of 15,000 volts are commonly specified and a range of relays to meet such requirements is available.

The source of D.C. for line signalling is isolated from the power mains by the use of primary batteries or secondary cells. Alternatively, a suitably isolated rectifier unit is installed together with provision for standby operation from a secondary battery.

A.C. SIGNALLING.

The use of alternating current for signalling not only simplifies the means of isolation but also enables several signals to be transmitted simultaneously by the use of suitable frequencies and filters.

The frequency of alternating current used is determined by (*a*) the frequency characteristics of the circuit over which it has to be trans-

mitted, and (*b*) the other services simultaneously required on the circuit. As the circuit is likely to be designed as a speech frequency circuit the signal frequency will lie in the speech band, say, between 300 and 4,000 c/s. Lower frequencies of the order of 50 c/s are occasionally used when the line characteristics are suitable and a limited number of facilities is required.

By the use of signal frequencies in the speech band, signalling is effected over any communication circuit, whether physical or phantom, a power line carrier circuit, or radio link. By suitable filters all speech frequencies above, say, 2,500 c/s can be cut off without serious impairment of speech, thus leaving a band 1,500 c/s wide, from 2,500 c/s to 4,000 c/s, for signalling currents. With band-pass filters a number of frequencies can be used simultaneously on the circuit without mutual interference with speech. Contacts of the supervisory relays are then used to chop the signal frequencies, and amplifier-detectors at the distant end of the circuit operate relays, which then repeat the pulses from the originating end of the circuit. In a power-line carrier circuit the voice frequencies may be fed to the carrier circuit and passed over it in the same way as speech.

Methods of Impulsing.

Interlaced Impulses.

When the channel signalling scheme permits signals to be passed simultaneously in both directions, interlaced impulsing is almost always used in G.E.C. systems for inter-station signalling. This system, unlike those which transmit control operations and indications by a train of timed pulses, does not require specially-adjusted relays. Control and indication signals are transmitted by interlacing the signals sent out from the control station with the signals returned from the substations, so that the cycle of operations is checked stage by stage. With such an arrangement, the selection relays and selectors are not called upon to operate and release in a fixed time, each relay and selector involved in the cycle of operations being given its own time. Consequently, automatic compensation is obtained for variations in battery voltage and relay adjustment.

Further, should a fault occur, the sequence of operations can be arrested at the appropriate point in the cycle, thus facilitating fault location.

Normally, a faulty point[1] does not interfere with the selection and indication of all other points since the equipment automatically steps over a faulty point circuit. For fault location, a key is provided which, on operation, disconnects the automatic step-on feature enabling the equipment to be brought to rest on the faulty point. The number and position (control station or substation) of the point are displayed on lamps.

Total Code Check.

Where there are only two pilot wires available and the number of control and indication facilities

[1] An outlet on the supervisory control selector or distributor from which any two-position device such as a circuit breaker can be indicated, or controlled *and* indicated.

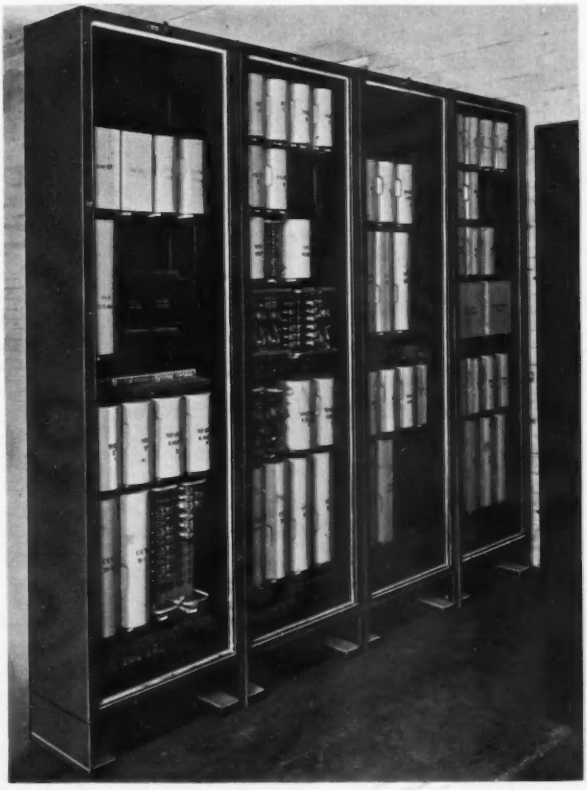


Fig. 13.—Selective and control apparatus cabinets at Spondon Generating Station, Derbyshire.

required is too small to warrant the cost of voice-frequency signalling equipment, a simple system is installed. In this system impulsing over the pilot wires is either by direct current or low-frequency alternating current, the signals being passed in only one direction at a time. The method used for checking selection is that known as the *total code check*. This uses a constant number of impulses in the train, irrespective of the information to be transmitted. The information is inserted into the train by altering the character of certain of the pulses.

System Types.

The four main types of G.E.C. system differ chiefly in the number of control and indication facilities provided.

System A : Non-Tandem.

This system provides for all the normal control and indication facilities for a substation of average size.

(1) Type of signalling channel—any.

(2) Number of pilot wires required :
D.C. signalling—four.
V.F. signalling—two.

(3) Operating voltage—50 volts.

(4) Signalling system—interlaced impulsing.

(5) Apparatus employed—relays and uniselectors.

(6) Number of control and indication facilities—46. Each indication, or control plus indication, facility requires only one point.

(7) Time for control selection—average of 4 seconds.

(8) Time to transmit indications—1 to 10 seconds.
On the occurrence of a change in the position of any item of indicated equipment all 46 points are automatically checked, the more urgent indications being transmitted first.

(9) Meter facilities : when D.C. signalling is employed, metering current can be superimposed on two of the four pilot wires for *on demand* meter indications or for the *continuous* indication (other than when the equipment is in use for supervisory purposes) of one selected quantity.
When V.F. signalling is employed, meter indications are transmitted either in the form of a code or by the variable-frequency method. A description of these systems will be found on pages 190-192.
A number of semi-continuous meter indications can be provided by employing the coding system, arrangements being made to transmit a complete set of new readings at intervals of, say, 2, 4 or 6 minutes as required, the indications displayed on the meters corresponding with the readings last transmitted.

(10) Telephony. With D.C. signalling, telephony can be provided over two of the four pilot wires whenever these are not engaged for the transmission of supervisory control signals.

When A.C. signalling is employed and the signalling channel is one over which frequencies up to, say, 2,500 c/s can be transmitted, suitable filters permit speech and supervisory control signalling to occur simultaneously without mutual interference, frequencies above 2,000 c/s being used for supervisory control and the frequency band below 2,000 c/s for speech. When, owing to the channel characteristics, the lower frequencies must be used for supervisory control signalling, the channel can be employed for telephony when it is not engaged by the supervisory control equipment.

System B : Multi-group and Tandem Working.

This system provides for the indication, or control plus indication, of 10 groups, each of which has a capacity of 46 points, selection being in two stages. In the first stage, the required group is selected, and in the second stage, the required point within the group is selected.

For multi-group working all groups can, if necessary, be installed in one substation and thus provide a maximum of 460 points.

For tandem working a common control station selector unit and a common signalling channel are employed and the groups are installed singly or in combination in the different substations.

In all other respects the particulars given under System A apply also to this system.

System C : Non-Tandem—All Relay.

This system has been designed chiefly to meet the demand of authorities operating larger interconnected power systems, such as the British Grid, from a Load Dispatching Office. It is therefore chiefly a back indication system, operation of switchgear being carried out by the generating station or substation staffs on telephoned instructions from the Load Dispatch Office. However, provision is made for a limited number of control facilities. Switchgear and

continuous meter indications are transmitted over the same channel and by the same selection equipment. The capacity of the system is sufficient to meet the requirements of the largest station. Since a large number of continuous meter indications can be transmitted, the selection equipment is subjected to duty more arduous than that performed by the smaller systems. Consequently, relays only are used to carry out all functions, since they have a much longer life than the uniselector.

(1) Type of signalling channel—any.
(2) Number of pilot wires required when D.C. signalling is employed—alternative systems for 2 or 4.
(3) Operating voltage—50 volts.
(4) Signalling system—interlaced impulsing.
(5) Apparatus employed—relays only.
(6) Number of indications—64 groups of 6 indications.
Each group can be used for the indication of 6 two-position devices, such as circuit breakers or for 1 multi-position device such as a transmitting meter.
(6a) Number of control functions—64.
(7) Time to transmit a control operation—2 seconds.
(8) Time to transmit indications—4 seconds. On the occurrence of a change in the position of an item of equipment all six points in the group concerned are automatically checked.
(9) Metering facilities. A coding system is used and any number of continuous indications up to a maximum of 64 can be transmitted.
(10) Telephony. If D.C. impulsing is employed and a number of meter indications is required, telephony can be provided over the same pilot wires if the meter signals may be withheld while the telephone conversation is in progress.
The one channel can be used simultaneously for speech and supervisory control signalling if voice frequency signalling currents are used in association with high- and low-pass filters.

System D: Small Capacity—Tandem.

This system is designed to control and back indicate a relatively small number of circuit breakers in each of a number of substations up to maximum of 20.

(1) Type of signalling channel—any.
(2) Number of pilot wires required when D.C. signalling is employed—2.
(3) Operating voltage—50 or 24 volts.
(4) Signalling system—total code check.
(5) Apparatus employed—relays and uniselectors.
(6) Number of control and indication facilities in each substation—8.
If one or two of the substations require a control and indication capacity in excess of eight then two units can be installed in these substations, the only limitation being that the total number of substation units should not exceed 20.
(7) Time to transmit a control operation—4 seconds.
(8) Time to transmit indications—4 seconds. On the occurrence of a change in the position of any item of indicated equipment, all eight points in the substation concerned are automatically checked.
(9) Metering Facilities. No particular provision is made for telemetering, but if a second pair of pilot wires is available selection points on the supervisory equipment can be used to connect, one at a time, any suitable type of telemetering transmitter at any of the substations to this second pair of pilots.
(10) Telephony. Telephony can be provided over the signalling pair, though an additional pair is to be preferred, since, if the one pair is used for the two functions, telephone communication is likely to be interrupted by supervisory signals.

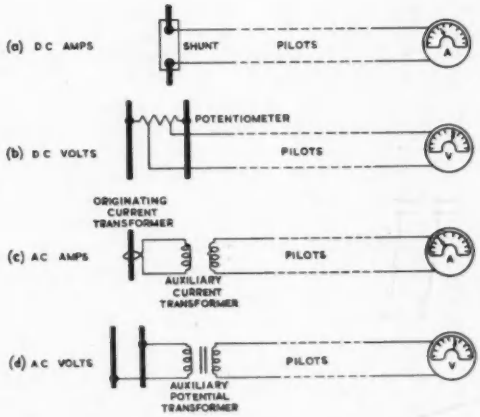


Fig. 14.—Direct metering :
(*a*) and (*b*) direct current and voltage ;
(*c*) and (*d*) alternating current and voltage.

REMOTE METERING SYSTEMS.

In most supervisory control systems the provision of meter and similar indications is essential for efficient control. Indications of the amps., volts, watts, flow, pressure, position and level at the remote substations constitute information vital to the controlling officer.

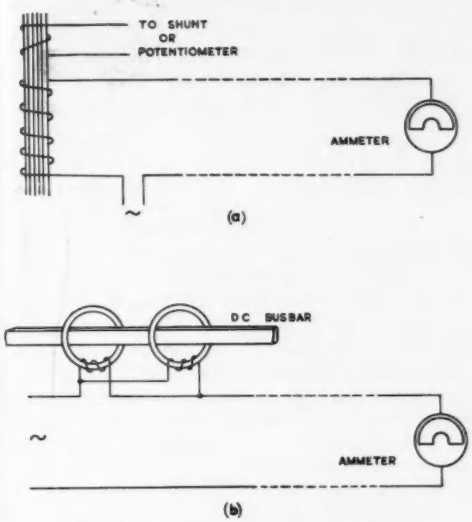


Fig. 15.—D.C./A.C. transformer metering.

DIRECT METERING.

The simplest form of remote metering is that in which the metering current is passed from auxiliary current or voltage transformers or from a shunt or potentiometer directly over pilot wires to the indicating meter, as shown in fig. 14. This is termed direct metering and if continuous meter indications are required a separate pilot wire circuit must be provided for each meter indication. If, however, observation of only one meter reading at a time suffices, the metering pilots can be switched, via the supervisory equipment, to any source of metering supply and to the associated indicating meter. This is termed " on demand " metering.

In A.C. measurements, the currents and voltages applied to the pilot wires can be restricted by suitably designed auxiliary transformers, but with direct D.C. measurement the pilot cables must be capable of withstanding the pressure of the D.C. system. This is not always practicable and special measures are sometimes taken virtually to transform the D.C. into an alternating voltage of comparatively low maximum value. The two most common static methods are illustrated in fig. 15. In fig. 15a one winding of a transformer is connected to the D.C. metering source (shunt or potentiometer) and the other to a 50 c/s alternating current supply via the indicating meter. The core of the transformer is magnetised to a degree dependent upon the direct current flowing ; therefore any change in the value of the direct current results in a corresponding change in the inductance of the winding connected to the A.C. supply. The value of current flowing in the A.C. circuit is therefore controlled by the current flowing in the D.C. circuit and thus the direct current or voltage can be indicated on the A.C. meter, which is calibrated accordingly.

An alternative method of indicating direct-current strength by means of A.C. is illustrated in fig. 15b. Two choke coils are fitted around the actual D.C. busbar. The busbar serves a similar purpose to the D.C. winding in the system shown in fig. 15a, the cores of the chokes being magnetised to a degree dependent upon the direct current flowing. Thus the greater the saturation of the choke cores by the D.C., the less will be the choking effect of the coils and consequently more alternating current will pass at any given voltage and frequency. Two coils are used in order to deal with both halves of the A.C. wave, the A.C. turns being wound in the opposite senses on the two cores. Where large direct currents are involved this system of metering will usually prove to be less costly and less wasteful of power than the more usual system employing a shunt.

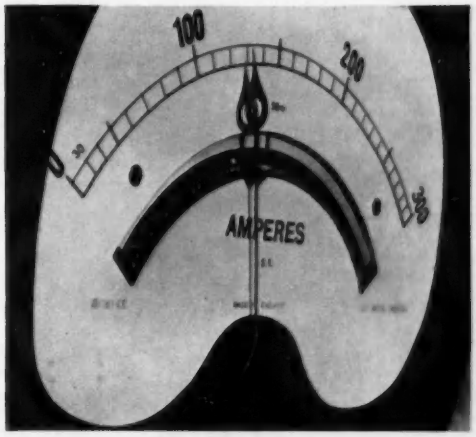


Fig. 16.—Ammeter with arc of contacts for transmission of readings.

Indirect or Coded Metering Systems.

Where pilot wires are not available for direct metering the measured quantity is translated into a code, of a form that can be transmitted over any type of signalling channel.

There is a very wide variety of coded metering systems. A selection of the systems most commonly used is given below ; one or other of these will fulfil almost any metering requirement.

Clutched Pointer System.

This system can be used for on-demand readings of any electrical quantity. The transmitting instrument consists of an indicating meter, modified as shown in fig. 16. To the pointer is fixed a small contact spring which moves over, but does not touch, an arc of contacts. The meter is connected to the source from which a reading is required by a selection operation over the supervisory apparatus. After a delay sufficient to ensure that the pointer has come to rest it is pressed back and held by a bar which is actuated by two small electromagnets. In this way, the contact spring carried by the pointer is brought into contact with one of the contacts in the arc. The supervisory control apparatus at the substation responds to the circuit thus established and sends impulses over the signalling channel. The number or code of the impulses is dependent upon the position of the pointer. At the control station, a selector is positioned according to the number or code of the impulses received and causes the indicating meter with which it is associated to be deflected to agree with the position of the transmitting meter.

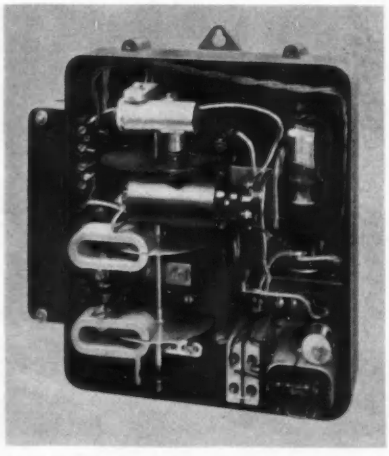


Fig. 17.—Variable frequency transmitting meter incorporating photocell and amplifier interrupter.

Variable Frequency System.

The transmitting meter used in this system is shown in fig. 17. By means of this meter, indications, faithfully following all fluctuations, may be given continuously or on demand and a number of indications from different meters may be transmitted simultaneously over a single channel.

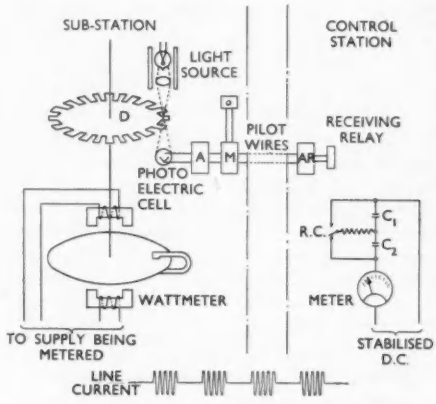


Fig. 18.—Principle of remote metering employing photocell.

The meter illustrated incorporates mechanism similar to that of a watt-hour or ampere-hour meter, in which a disc on the shaft has a series of slots in its periphery. Rotation of the shaft causes the slots to pass between a source of light and a photocell, the path of light being thus interrupted at a rate which, being dependent upon the speed of rotation, is proportional to the quantity being measured. This action, represented diagrammatically in fig. 18, gives rise to variations in potential which are impressed on the grid of a valve. This valve serves as an amplifier of the output of an oscillator but, when the photocell is conductive the potential impressed on the grid of the valve biases it to such an extent that current cannot pass to the pilots. The output of the oscillator is thus interrupted at a speed dependent upon the speed of rotation of the disc. The interrupted current passes over the pilots to the control station, where rectification by an amplifier-rectifier produces a current of frequency equal to that of the original

variations. A receiving relay responds and alternately charges and discharges two capacitors. A meter measures the charging current and thus provides an indication proportional to the quantity to be measured.

By the use of oscillators generating different frequencies, together with suitable filters, a number of indications can be sent simultaneously. Further, these may be sent over a signalling channel actually in use for telephony or remote control of plant.

The same principle may be employed for the reading of any meter or similar device in which rotary speed varies with the quantity to be measured.

Torque Balance System.

This system can be used for almost any kind of measurement. There are various patterns of transmitter to suit the particular information to be transmitted. Those used for the measurement of electrical quantities contain measuring instruments, while those used for indications such as water levels and gas pressure are mechanically coupled to the level or pressure detection mechanisms.

The principle of operation is illustrated in fig. 19, which shows a wattmeter transmitter. A contact carried on the pointer of the wattmeter movement lies between two outer fixed contacts. So long as equilibrium exists between the torque of the movement and that of the balance spring, the centre contact floats freely between the two outer contacts. However, as soon as there is any increase or decrease in the watts measured, the centre contact touches one of the outer contacts, thereby energising one of the two fields of a small motor. According to the direction of rotation, the motor winds or unwinds the balance spring on the spindle of the movement until equilibrium is again established between the two opposing torques, when the contacts part and thus open the circuit of the motor. The shaft that winds the balance spring also carries a contact arm, which rotates over an arc of studs ; these are connected to the supervisory apparatus. The position of the moving arm bears a direct relationship to the measured quantity and, according to the stud marked by the contact arm, a code is transmitted to the control station to cause the quantity measured to be displayed on the associated meter.

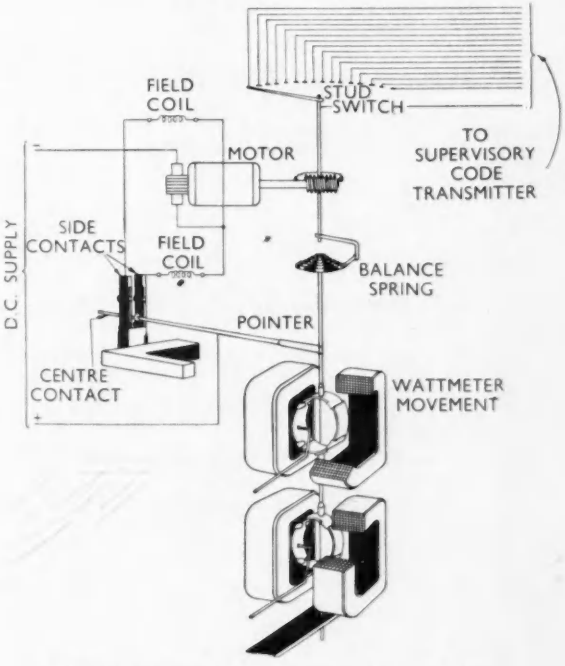


Fig. 19.—Torque balance telemetering transmitter.

The position of the contact arm on the arc of contacts is transmitted in the form of a binary code, the number of contacts in the arc being one that can be expressed as 2^n. The actual number of contacts used is usually 64 which is equal to 2^6. Thus by transmitting a code consisting of six elements, each of which can take one of two forms, any one of the 64 positions can be indicated. If the number of contacts in the arc is 128 then the code consists of seven elements of one of two forms. By the application of this form of coding, rapid response is obtained while the signalling apparatus is subjected to the minimum of wear.

At the control station the code, assuming that a 64-position transmitter is used, is received on a group of six relays which control resistors in the circuit of a milliammeter that displays the required indication. Depending upon the combination in which these relays are operated, the meter is deflected to one of the 64 segments into which the arc of the movement is, in effect, divided. When the relay

associated with the first code element is operated, it causes the meter to be deflected over 32 segments, the relay associated with the second code element causes deflection over 16 segments and the following relays over 8, 4, 2 and 1 segments respectively. If none of the relays is operated, the meter reads zero ; if they are all operated, full scale, and if, for example, the first and third are operated the meter is deflected to the position equivalent to five eighths of full scale.

The main advantage of this system is that it enables a number of virtually continuous meter indication to be transmitted by the same supervisory apparatus as that employed for the back indication of circuit breakers and other switchgear, arrangements being made automatically to transmit a new reading when a change equivalent to a minimum of 1/64 of the full scale reading occurs.

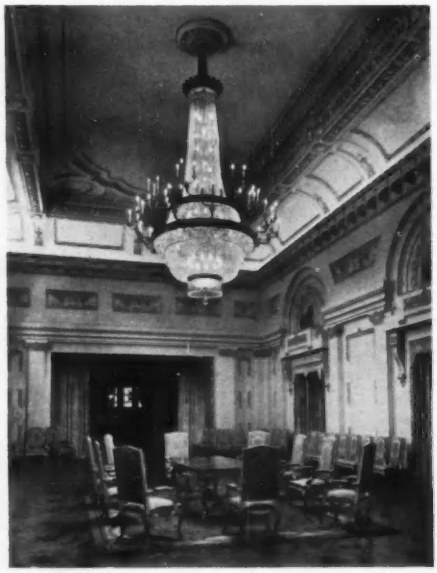
IMPULSE INTEGRATION SYSTEM.

In this system the impulses delivered from the commutator or other impulsing device of a watt-hour, VAr-hour or ampere-hour meter are counted for a period of one, two, three or four minutes, and at the end of the period an associated indicating meter is deflected to a position dependent upon the number of impulses counted. Thus if, for example, 64 impulses are delivered at maximum load, i.e., at full scale reading of the indicating meter, a count of 32 impulses will cause the meter to be deflected to half scale, and so on.

Indications are transmitted in one of two ways depending upon the general requirements. In one method, each impulse as delivered from the transmitting meter is passed over the signalling channel to a counter at the control station. In the second method, the impulses from the transmitting meter are counted at the substation, and at the end of the count period the number counted is transmitted to the control station by the supervisory equipment in the form of a binary code.

The greater the number of impulses counted the greater the metering accuracy, but the longer the count period the greater will be the delay in indicating load fluctuations. In the G.E.C. system a compromise is made between these two conflicting requirements of accuracy and quick response. Arrangements are made in the counter to detect the trend of the load and to transmit approximate indications at each quarter of the full count period if it is found that the indication being displayed is inaccurate by ± 25 per cent of the full scale reading.

The Banqueting Hall at Lourenço Marques



This crystal chandelier was designed and executed by G.E.C. craftsmen as the central lighting and decorative feature in the Banqueting Room of the Town Hall at Lourenço Marques.

11 kV Distribution Switchgear

By C. J. O. GARRARD, M.Sc., M.I.E.E.
Witton Engineering Works.

Following the decision of the British Electricity Authority to begin the construction of a supergrid at 275 kV, the author attempts a forecast of the way in which distribution networks are likely to develop. Special consideration is given to probable requirements in distribution switchgear. This involves the question of planning the 11 kV distribution systems for the most economical short circuit levels in main and network substations.

THE PLANNING OF DISTRIBUTION NETWORKS

THE decision by the British Electricity Authority to begin the construction of a supergrid at 275 kV makes it possible to attempt a forecast of the manner in which distribution networks in this country are likely to develop, and therefore to estimate the probable requirements in distribution switchgear.

The short circuit level of the 132 kV grid, which was designed originally to be 1,500 MVA, has already risen in many localities to 2,500 MVA and in some has exceeded this value. It appears that 3,500 MVA is the maximum economic rating for which 132 kV circuit breakers can be built, and it follows from this that the imposition of the 275 kV network upon the 132 kV grid will necessitate the subdivision of the latter.

Similar arguments apply to the lower voltage distribution networks which obtain their power from the 132 kV grid. The degree of subdivision of these that will be necessary is again governed by the range of economic ratings of switchgear at the various voltages. Fig. 1 shows what, in the author's opinion, are these ranges of economic ratings and also the maximum practicable rating at each voltage.

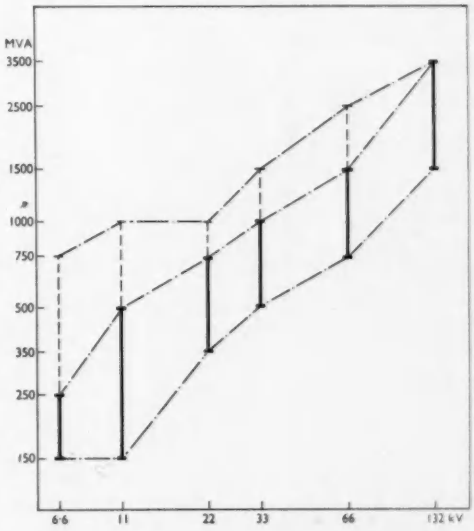


Fig. 1.—The heavy vertical lines indicate the economic breaking capacity ranges of switchgear for different service voltages. The vertical broken lines show the maximum practicable range at each of the different voltages.

The desirability of keeping towards the lower end of the scale of breaking capacity at each voltage is illustrated by fig. 2, which shows the approximate variation of cost with breaking capacity of typical metal-clad units at different voltages. The cost of the lowest rating in each voltage category has been taken as unity in each case.

One is thus led to a picture of an integrated distribution system consisting in the first place of a single backbone in the shape of the 275 kV grid (fig. 3). The short circuit level of this network is unlikely to be less than 5,000 MVA and may be 7,500 MVA.

The existing 132 kV network one imagines divided into a number of areas corresponding possibly to the present Divisions of the British Electricity

Authority, although it may be that, in the future, even smaller subdivisions may be necessary in order to prevent the short circuit level exceeding, say, 3,500 MVA.

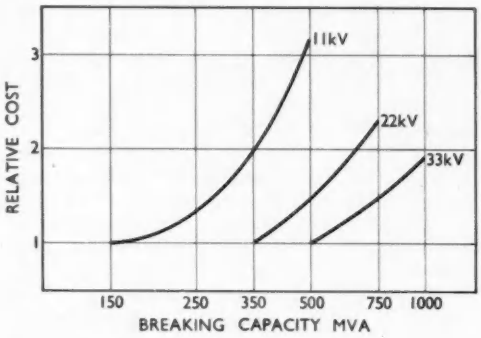


Fig. 2.—Variation of the relative cost of metalclad distribution switchgear as a function of the voltage and breaking capacity. The lowest capacity at each voltage is taken as unity for that voltage.

It is probable that the main part of the generating plant will in the future be connected directly to the 275 and 132 kV networks. Only in very densely populated areas will power stations feed into the lower voltage networks.

Distribution will presumably be carried out at 66, 33 and 11 kV by extension and reinforcement of the existing networks.

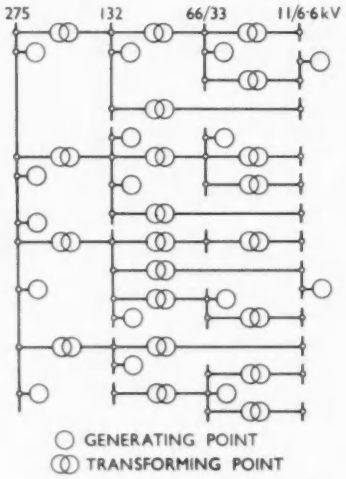


Fig. 3.—Diagrammatic representation of the national supply and distribution network.

A high degree of subdivision will, however, be necessary in order to keep the short circuit levels within the limits at which switchgear can be economically provided.

The final high voltage distribution networks will thus consist of a large number of blocks, each supplied by two or more transformers from a higher voltage sector.

In fig. 4 is shown a set of curves which give the short circuit level of such a block as a function of the capacity of the transformers by which it is fed, and the short circuit level of the higher voltage network to which these are connected.

These curves can give only a general picture of the problem of choosing the most appropriate short circuit level for the lower voltage network and they apply, of course, only to the main substation gear which is immediately adjacent to the transformers.

Nevertheless they illustrate very strikingly that if 11 kV switchgear is to be confined to the very economical 150 MVA range, the associated transformer capacity must be reduced to the order of 20 MVA, even when the primary net-

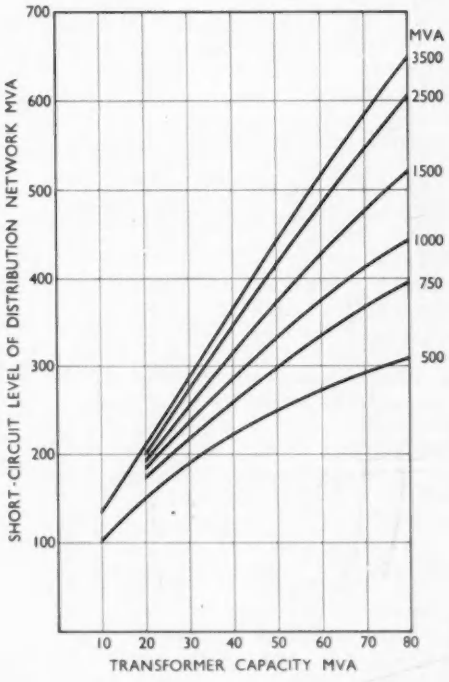
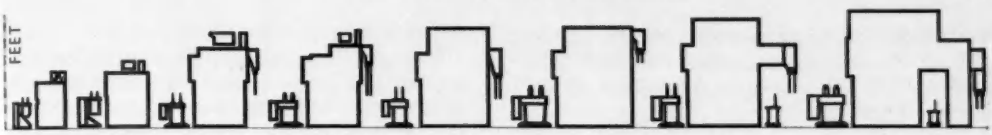


Fig. 4.—Distribution network short circuit level as a function of the main transformer capacity and the short circuit level of the network to which they are connected.



	(a)	(b)	(c)	(d)	(e)	(f)	(g)	(h)
Type	KSB 4/2	KDS 5	KDS 6/2	KDS 6/2	KDS 7	KDS 7	KDS 9	KDO 8
Voltage kV	6.6/11	6.6/11	22	6.6/11	33	6.6/11	33	11
Breaking Capacity MVA	150	250/350	350/500	500	750/1000	750	1500	1000
Normal Current Amps	800	2000	800	2000	1200	3000	2000	4000

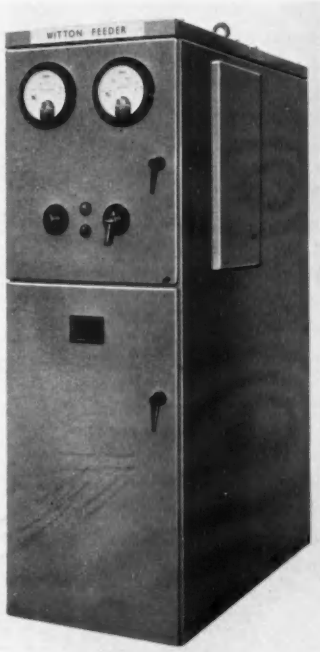
Fig. 5.—Outlines drawn to scale of a range of metalclad switchgear.

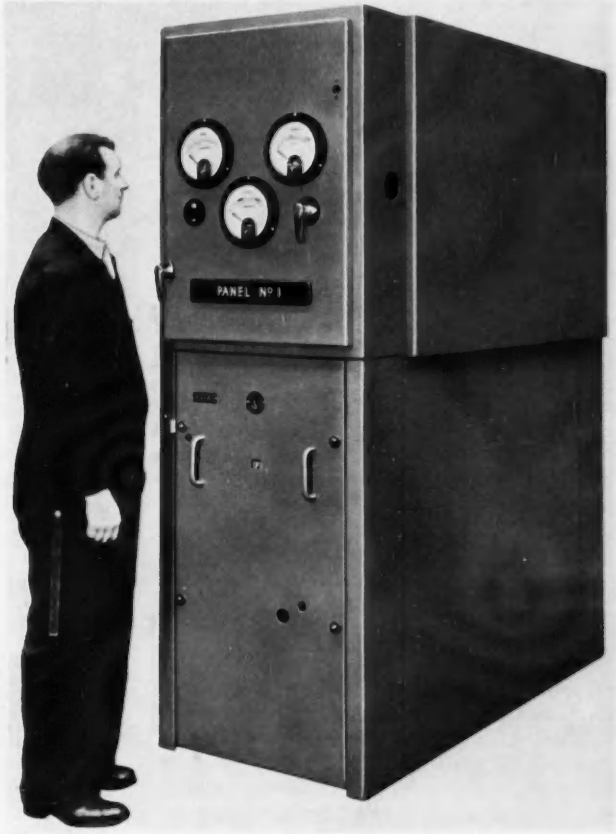
work has the comparatively low short circuit level of 500 MVA.

If the short circuit level of the distribution network is raised to 250 MVA, the transformer capacity may be raised to between 30 and 50 MVA depending on the size of the higher voltage system.

The problem is entirely different if generating plant of any considerable capacity is connected to the 11 kV bars ; the short circuit level can then scarcely be less than 500 or 750 MVA. Such cases are, however, outside the scope of this article.

The general conclusion to be drawn from these considerations is that, in the interests of economy and convenience, 11 kV distribution systems should be so planned that the short circuit level





Figs. 6 and 7.—Typical 150 and 350 MVA metalclad distribution switchgear units.

in the main substations is within the 250 to 350 MVA range ; this in turn will enable the majority of the network substations to be equipped with gear of 150 MVA capacity.

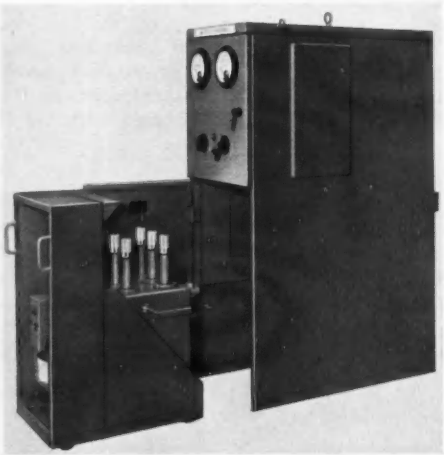
In terms of normal current rating such a plan would call for units up to, say, 1,600 amps. in the 250-350 MVA range in order to provide for the connection of transformers up to 30 MVA ; in the case of a network running at 6·6 kV 2,000 amp. units might be required. For the 150 MVA gear, on the other hand, it should be possible in most cases to arrange for the normal current not to exceed 800 amps.

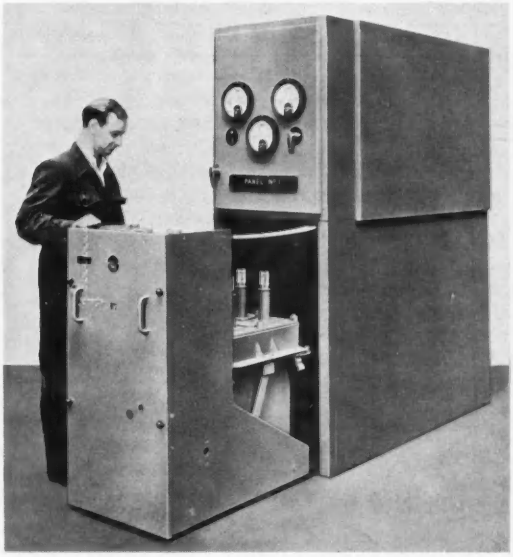
In the heavier gear double busbars will doubtless be necessary in some cases, although in the majority of instances and in practically all cases at 150 MVA, it should be feasible, in the interests of economy, to manage with single busbars.

In the remaining part of this article it is proposed to describe briefly a range of metalclad switchgear which is designed to satisfy the requirements which appear to result from the above arguments.

It is hoped that the description of the gear will be interesting, not only as one solution of the problem of providing an economical range of distribution switchgear, but also as an example of the application of modern fabrication methods to switchgear manufacture.

Figs. 8 (*below*) and 9 (*right*).—The units shown in figs. 6 and 7 with circuit breakers withdrawn for inspection.





SCOPE OF THE RANGE OF GEAR.

A general impression of the gear under consideration is given by figs. 6 and 7 showing respectively a 150 MVA unit and a 250 or 350 MVA unit. Fig. 5 shows, for the sake of comparison, the relative sizes of the complete range of 11, 22 and 33 kV units of which those at present in question form a part.[1]

This article deals with the ratings given in Table 1, although the ratings given here may possibly, as the result of experience, be supplemented in some directions.

The units are of the vertical isolation type, are entirely of fabricated steel construction and completely enclosed in dust-proof housings.

Each unit is self-contained and consists of a fixed part comprising a pair of pedestals which carry the busbar and current transformer chambers and a circuit breaker mounted on a carriage with integral hoist gear (figs. 8 and 9).

In double busbar units, selection of the busbar is made by lowering the breaker, moving the breaker carriage bodily backwards or forwards and raising the breaker into the new position.

The larger breakers are of the conventional double-break type (fig. 10), while the 150 MVA units have single-break breakers (fig. 11) ; all

[1] See *G.E.C. Journal*, Feb. 1943.

breakers are fitted with G.E.C. side-blast arc control pots.

In addition to the standard units a series of isolating switches is available by means of which the usual arrangements of ring main isolator units may be built up. The isolators are all suitable for being closed upon a fault without damage to the switch or danger to the operator.

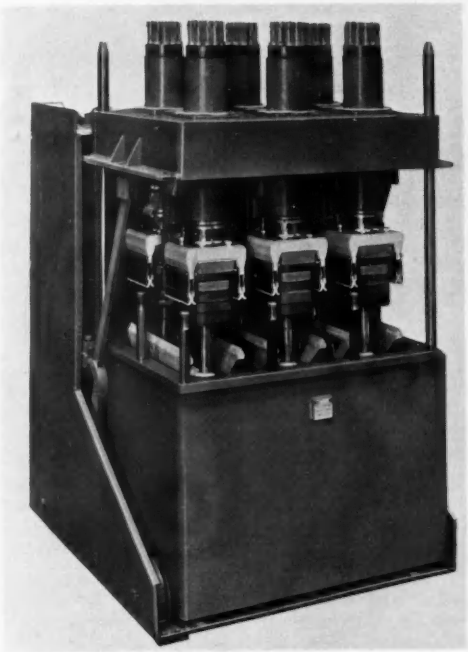


Fig. 10.—An 11 kV 250 MVA, 2,000 amp. circuit breaker.

CONSTRUCTIONAL FEATURES.

In the construction of the gear the fullest advantage has been taken of modern methods of fabrication in which plates are prepared in the flat by notching and piercing with a turret press, then bent in a press-brake and finally welded, or in some cases as described below, riveted.

As an illustration one may take the fabricated pedestals of the 250 MVA unit, the design of which takes advantage of methods developed for aircraft construction, and comprises (with the exception of certain small mechanical details) only five parts. Each pedestal consists of a steel plate bent into a shallow box section and riveted at the top and bottom to bent-up channels. By this means, a light and strong structure is achieved, and it is found that the riveting, which is done by means of an automatic gun, is quicker and cheaper, and gives rise to less trouble from distortion, than welding; furthermore the absence of welding imposes no restrictions on the choice of gauge of metal, which can be made solely with regard to the necessary stiffness of the structure.

In the busbar chambers the number of main parts has been reduced to four for each chamber, that is, a main plate which is notched and pierced in the flat, bent and welded to two flanges, and to a bottom plate which carries the isolating contact spout insulators. The flanges and the bottom plate are machined and drilled before assembly, so that the chamber leaves the welding jig complete. The current transformer chamber is made similarly, but as it is of more complicated shape the number of parts is larger.

The breaker carriage consists of a number of flat trays each made by bending up and welding the edges of a suitably profiled steel plate. These trays are then bolted together to form a light but strong structure.

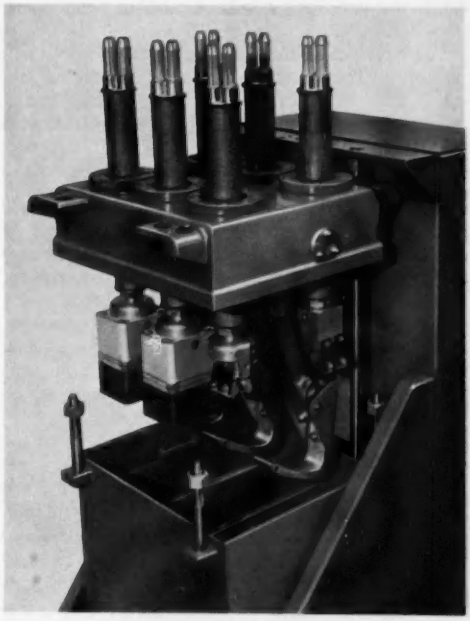


Fig. 11.—An 11 kV 150 MVA, 800 amp. circuit breaker. One arc control pot has been removed to show the fixed contacts.

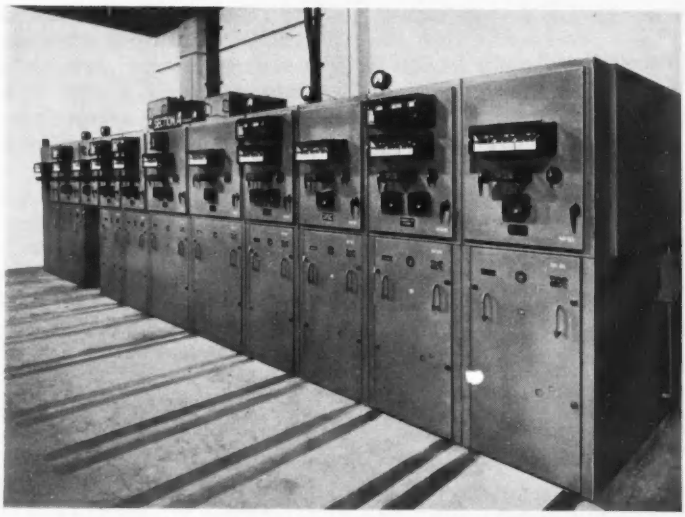


Fig. 12.—An 11 kV 350 MVA distribution switchboard in a city substation.

TESTS AND PERFORMANCES.

The units are fully tested in accordance with British Standard No. 116. In addition, they are tested in accordance with Canadian Standards at 4, 7·5 and 15 kV with a view to their use in that country.

The results of the tests are in every way satisfactory. The arcing time at 11 kV and at the maximum rating in no case exceeds 2 half-cycles, while the opening time is 2½ cycles (0·045 sec.). The make time is 12 cycles (0·24 sec.). On tests to prove the normal current capacity, the maximum temperature rise of any circuit carrying part is 35 degs. C. on an 800 amp. unit, and 40 degs. C. on a 1,200 amp. unit.

TABLE 1.

Breaking Capacity MVA	Normal Current Amperes
150	400 800
250	400 800
350	1,600 and 2,000

An Electrical Dynamic Balancing Machine for Turbo-Alternator Rotors

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Development Laboratory, Witton Engineering Works.

In the past, the dynamic balancing of large rotors has been a long and costly procedure. This article deals with the theory and design of an electrical balancing machine developed at Witton Engineering Works for this class of work.

This machine can accommodate a wide range of rotors, and determines both the sizes and positions of the balancing weights required. The accuracy of this method of balancing is more than equal to that of the old trial-and-error method and the saving in time is very considerable.

INTRODUCTION.

THE dynamic balancing of large rotors has always been a major problem. The usual method not only takes considerable time, but necessitates running at full speed with consequent considerable discomfort to the operator. As an example, a 30 ton turbo-alternator rotor has to be run in a safety pit and may take about six days to balance. During this time large amounts of power have been consumed, at least two skilled men have been employed and at least one of them has been subjected to some danger and discomfort from the partially balanced rotor running at speed. In the absence of several such safety pits dynamic balancing may also constitute a bottle-neck in production.

Some form of balancing machine is obviously desirable and this article is concerned with the construction of such a machine at the Witton Works.

SPECIFICATION.

The Development Laboratory was asked to produce a machine which would satisfy the following requirements :

1. The machine had to accommodate all normal rotors from 5 to 40 tons in weight.
2. It had to indicate the position as well as the size of the dynamic balance weights required.
3. Its accuracy had to be at least equal to that obtained by the older trial methods. In effect this meant that the machine would have to work to fractions of an ounce at the rotor periphery.
4. It had to be capable of operation in the open shop. This limited the speed to about 600 r.p.m.
5. All rotors had to be regarded as different so that calibration for each rotor had to be made easily.
6. The ordinary shop personnel had to be able to operate it successfully.

GENERAL THEORY.

In any dynamic balancing machine the fundamental problems involved are the obvious ones of sensitive indication of the value of the balance weights required and their position, and the not-so-obvious one of the isolation of the unbalances at each of the balancing planes. The latter requires some explanation.

Any number of unbalances can, for practical purposes, be regarded as the equivalent of two unbalances only, one at each of the balancing planes. The balancing planes can be chosen for convenience and are usually the ends of the rotor. Dynamic balance is obtained by fixing balance weights opposite the two unbalances. Fig. 1 shows an unbalanced rotor in bearings. It is apparent that the vibration produced by the unbalanced centrifugal forces from the combined unbalances A and B can consist of a uniform or non-uniform lateral movement of the rotor, or a rocking motion due to couple effects or a combination of both movements at once, depending upon the relative circumferential positions of the weights. The obvious place to measure the movement is at the bearings (1)

and (2), although each bearing is unfortunately affected by both unbalances. For example, it is apparent that unbalance *A* will vibrate bearing (1) considerably, but there is present also some smaller vibration at this bearing from unbalance *B*. Measurement of the combined vibration at bearing (1) is not therefore a true measure of either of the individual unbalances *A* or *B*.

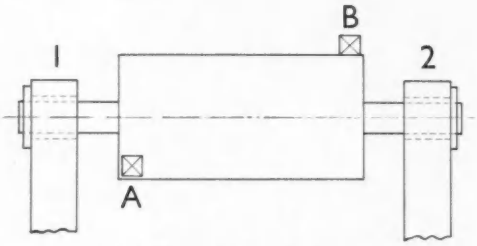

Fig. 1.—Simple dynamic unbalance.

The simplest method of isolating the effect of one of the unbalances is that used in mechanical dynamic balancers. It consists of mounting the bearings on a common rigid cradle which in turn is spring restrained and can rock about a pivot. Usually the pivot is vertical and the springs arranged to restrain the rocking movement.

The pivot point can be moved along the length of the cradle and is placed alternately under each of the balancing planes. When, for instance, it is under the plane of *B* it is apparent that unbalance *B* cannot rock the cradle about the pivot. Unbalance *A* can do so, however, so that measurement of the rocking movement against the spring restraint is a measure only of this one unbalance.

The alternative electrical method uses a network to produce the same effect and does not require a cradle. Before this method is considered in more detail, it is desirable to appreciate the general relative merits of mechanically and electrically operated machines, keeping the above points in mind.

MECHANICAL OR ELECTRICAL METHODS OF BALANCING.

For big rotors the disadvantages of the mechanical machine are considerable and the advantages appear to be negligible. First, the usual rocking cradle and movable pivot are awkward to handle when working on large rotors of the order of 40 tons weight. Second, the mechanical method involves running at a resonant speed to obtain sensitivity, and this requires extremely fine speed control to obtain the accuracy required. Third, position finding mechanically requires either skilled calculation or apparatus such as a countershaft carrying phasable and variable unbalances, which is difficult in such a size and in any case is not very accurate.

By comparison, the measuring gear on an electrical machine is small and independent of the rotor size, while the mechanical parts are extremely simple. These consist only of a bedplate, two flexibly mounted bearings and means for driving the rotor. In addition, the machine does not run at resonance and sufficient sensitivity can easily be obtained at very low speeds.

As an electrical machine of small size had worked very successfully, and in view of the considerations mentioned above, it was decided to adopt the electrical principle for the new big machine.

ISOLATION BY ELECTRICAL METHODS.

In the case of a rotor running in independent flexibly mounted bearings it has been shown that it is possible to isolate the effects of the unbalance at a particular plane by the use of electrical networks.[1] To do this, an electrical generating device operated by the vibration is required on each bearing, and the output from each of these must be a linear function of the size of the unbalance.

[1] BAKER and RUSHING, *Journal of the Franklin Institute*, Vol. 222, No. 2, August, 1936.

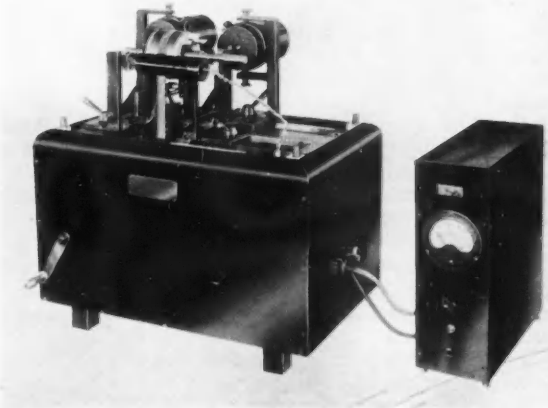

Fig. 2.—Small electrical balancing machine.

A simplified arrangement of the circuit is shown in fig. 3. Generators (1) and (2) are the magnet and moving coil systems. As the field and frequency are constant, the spring characteristic linear and the centrifugal forces caused by unbalance proportional to the size of the

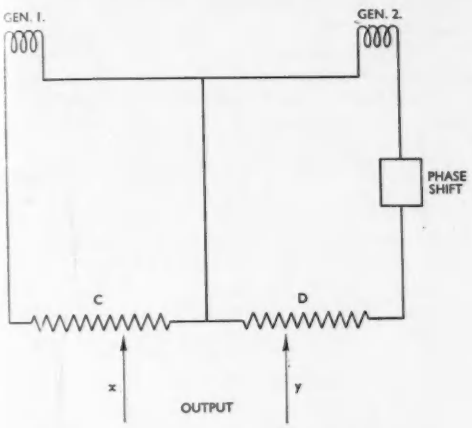

Fig. 3.—Simplified portion of mixing circuit.

unbalance, the generated voltage is proportional to the sizes of the unbalance forces. Unfortunately each generator voltage is still a function of both unbalances. The circuit shown isolates the voltage created by one unbalance in the following manner.

Assume that the only unbalance is at *A* (fig. 1). As the plane of *A* is closer to bearing (1), the voltage from generator (1) will be bigger than that from generator (2). After bringing the currents in the two halves of the circuit into phase with the phase shifter shown, it should be possible to find two equipotential points on the resistances *C* and *D*. If the movable contacts *x* and *y* are set to these points there will be no voltage across the network output. Similarly, any other unbalance on plane *A*, even if of different size, will produce no output. If now any rotor of similar shape and size having unbalances at both the planes *A* and *B* be put into the machine, any output must be created by unbalance *B* alone as unbalance *A* cannot have any effect. Isolation of one unbalance has thus been achieved.

Similarly, it is possible to obtain an output proportional to *A* alone by another setting of the circuit in which *B* cannot produce an output. In practice the tapping points *x* and *y*, and the phase shifter, are duplicated so that either setting can be obtained by simple switching.

This principle was used in a small balancing machine made during the war for the accurate balancing of large numbers of small D.C. armatures (fig. 2). The armature is belt-driven and its bearings hang on simple leaf springs so that either can move horizontally against spring restraint. The electrical generators are seen at the back; each consists simply of a permanent magnet field system in which a coil is moved by the vibrations of the rotor. The network and indicating means are on the right. This machine, with only one operator, is capable of balancing an 8 lb. armature to an accuracy of 1/1,000 oz. in. in an average time of six minutes including the fixing of the balance weights. The life of the amplifier valves, which were in use for the whole of each working day, proved to be years, rather than months.

DESCRIPTION OF THE LARGE MACHINE.

Rotor Mounting.

As the electrical system does not call for special cradles the mechanical parts are very simple. Fig. 4 shows a general view of the complete machine. Both bearing pedestal assemblies can be moved along the bed and the left-hand one carries the complete instrument and control panel. The length of the bed is sufficient to take the largest turbo-rotor contemplated. The bearings themselves are open-topped white-metal lined bushes arranged for easy interchanging so as to accommodate rotors of different sizes. A bearing with the oil covers removed is seen in fig. 5. Lubrication is by high pressure oil from two separate pumps with sufficient pressure to lift the journal. The three pressure gauges at each bearing are associated with this lubrication system. The overflow oil drains into a trough down the centre of the bed and back to the oil tanks. Each bearing rests in a vertically pivoted pedestal which hangs from two leaf springs. The left-hand spring is clearly visible in fig. 5. The spring system can be locked up by the smaller hand wheels visible in fig. 4.

Drive is by means of an uprated 75 h.p. D.C. motor, which is supplied with power from a Ward-Leonard set and operated from the main control panel. This motor will run a 20 ton turbo-alternator rotor up to the balancing speed of 600 r.p.m. in about two minutes. Dynamic braking is provided by regeneration on to the line and this enables the rotor to be stopped in about the same time. The drive is transmitted to the rotor through a short countershaft with a Hookes type universal coupling at each end. One coupling is free to slide axially in the usual way (fig. 6).

Vibration Voltage Generators.

Moving coil generators identical with those of the smaller machines are used ; these are not visible in the photographs as each is housed in the hollow outer bearing pedestal. This arrangement has the advantage that the only delicate part of the mechanical system is completely hidden and protected. In what follows these generators will be referred to as " vibration generators ".

Control Panel.

Fig. 4 shows clearly the position of the control panel and network circuits. The panel is fixed to the left-hand bearing pedestal and moves along the bed with it. To refer now to fig. 7, which shows the details of the control panel more clearly, the motor controls are in the lower half and the network and amplifier controls in the top half. The main speed controller is the largest handwheel on the panel and there is a fine controller above it. An emergency stop button is fitted.

The large central meter measures the amount of unbalance and immediately below it is the sensitivity control. Below, and next but one to this, is the switch that changes the network over from one setting to the other depending upon which of the two unbalances is required.

The extreme left-hand meter in the top row shows the speed of rotation and each of the other three small meters records the output of one of the three small alternators to be described later. To the right of the unbalance meter is the cathode ray tube. The remaining small knobs and buttons control the network, the alternators and the oscilloscope.

The Amplifier.

The output from the network is very small and has to be amplified considerably. However, it is first roughly filtered to remove a large proportion of any unwanted frequencies which may have crept in due to floor vibration, roughness in the bearings, or a thousand other ways known and unknown to engineers. The main purpose of this filtering is to avoid unnecessary overloading of the valves.

The amplifier is quite straightforward apart from the fact that, although amplifying A.C., the frequency of 10 c/s calls for rather large components in some places. A push-pull output is used to avoid a standing field in the meter which is direct-coupled to the output valves.

Step-by-step control of the sensitivity is provided. The maximum sensitivity is more than is actually needed for the accuracy of balancing required.

Unbalance Meter.

As explained earlier, various unwanted voltages caused by external vibrations appear in the network output. Although these are roughly filtered, a residue reaches the amplifier and it is

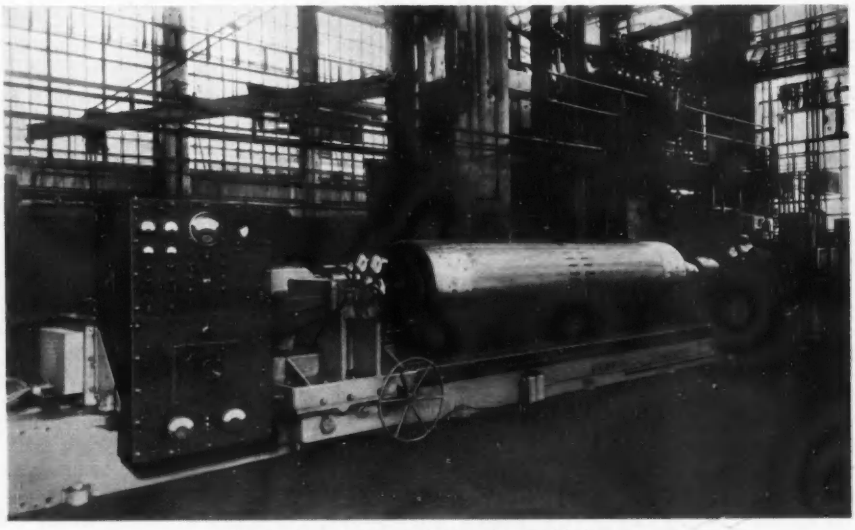

Fig. 4.—General view of large electrical balancer.

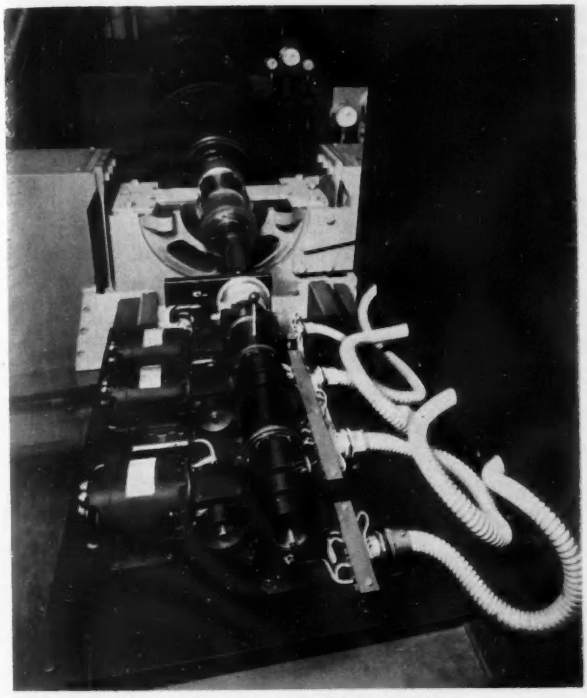

Fig. 5.—Spring suspension and alternators.

essential that this should not affect the meter reading. Therefore, instead of an ordinary voltmeter, measurement is made on an instrument wound rather as a wattmeter. One coil of this is fed from the amplifier and the other from a small alternator driven by, and at the same speed as, the rotor. The excitation from the alternator is constant and provides a field at unbalance frequency only. The needle deflection is caused by the interaction of the two fields created by the amplifier and the alternator, and is solely a function of the unbalance voltage which alone has a frequency common to both.

The small alternator is the one nearest to the rotor in fig. 5. In order that the reading should have a fixed meaning, the alternator voltage has to be brought into phase with that of the amplifier, and to achieve this the stator of the alternator is made rotatable. The operating motor for this purpose is controlled from the main panel. In practice, phasing merely means that the stator is turned until a maximum reading is obtained.

The scale of the meter is not calibrated directly in ounces as other variables make this difficult, the overall response is, however, always linear, so, for example, twice the reading indicates twice the unbalance.

Position Finding.

It is obvious that the instantaneous voltage generated as a result of one unbalance must at any moment depend upon the position of the unbalance in relation to the generating system, the latter being fixed in space.

As already mentioned, a small alternator is coupled to the rotor shaft. The instantaneous voltage generated by this alternator depends upon the position of its stator in relation to its rotor. The alternator rotor position bears a fixed relationship to the unbalance position as the two are solidly coupled.

The maximum positive voltage from the alternator and the vibration generator may not occur at the same instant, but by turning the stator of the alternator they can be made to do so.

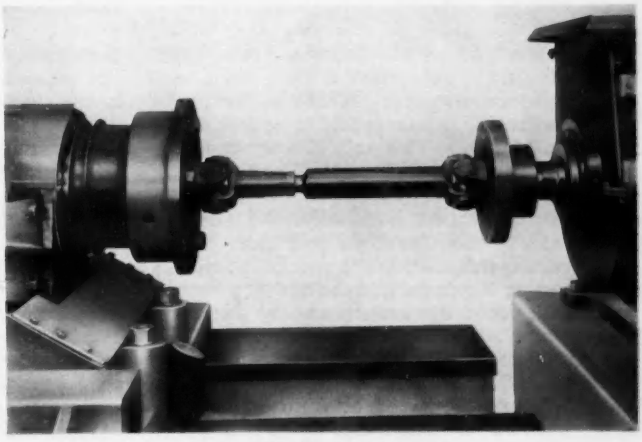

Fig. 6.—Flexible drive to rotor.

There is only one position of the stator that will satisfy this last condition and obviously it would be different if the position of the unbalance were moved round. Therefore the position of the stator is an indication of the position of the unbalance.

being in phase as mentioned above. The relationship is just as fixed, however, and the quadrative reading only is used as it is more critical to the alternator position than the maximum reading and therefore gives greater accuracy.

The rotor is then stopped and turned until a

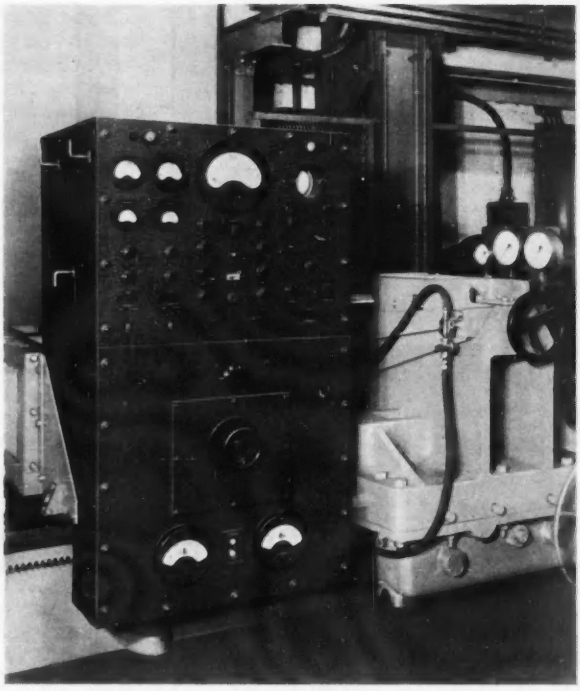

Fig. 7.—Control panel.

In practice, there are mechanical and electrical time lags in the system which cause a variation in the relationship of the position of the unbalance to the vibration generator system for maximum voltage. This calls for a separate calibration for each type of rotor. The explanation given above holds, however, and the position of the alternator stator is actually used as the indicator for the position of the unbalance.

The positioning procedure is as follows: The rotor is run at 600 r.p.m. and the reading on the unbalance meter is reduced to zero by turning the alternator stator. There are, unfortunately, two positions that will give this, but a particular one can be obtained by following a very simple drill. When this position is obtained, the alternator voltage is 90 degs. out of phase with the vibration generator voltage instead of the two particular point on a scale rotating with it is in line with a mark on the stator. The point used is one determined in the calibration which is described later. The unbalance is now in a fixed position relative to a mark on the main frame, this mark being that used during calibration.

As a check upon the accuracy of the positioning by the alternator stator an oscilloscope is provided. This is used to find another position, which should be 90 degs. round, where the alternator and vibration generator voltages are in phase just as in the preliminary exploration. The *X* plates of the oscilloscope are connected to the vibration generator output and the *Y* plates to the alternator output. When the alternator stator has been turned until the voltages are in phase a straight line appears. At all other positions the trace becomes a loop. Fig. 8

shows the appearance of the trace during the balancing of a 30,000 kW alternator when the voltages were in phase. Fig. 9 shows the trace obtained when the voltages were 10 degs. out of phase.

CALIBRATION.

It is apparent that the reaction of the machine to a particular unbalance will depend upon the position of the balancing plane and also upon the mass and shape of the rotor to which it is attached. To convert the reading obtained into a weight, therefore, requires a calibration for each new type of rotor. Similarly a calibration is required for positioning, as the mechanical time lags will vary with the mass of the rotor.

With the smaller electrical balancer, it was the practice to balance a dummy rotor as nearly to perfection as possible by trial and error. This rotor was then put in the machine and deliberately unbalanced, first in one plane and then in the other, by a known amount in a known position; the network was then set up with these weights and the reaction of the machine to them provided the calibration.

With the large rotors there is, of course, no possibility of using a perfectly balanced dummy. The difficulty is overcome by using the rotor which is to be balanced as the dummy and at the same time make the electrical circuits insensitive to the vibration caused by its own unbalance. In other words, so far as the electrical system is concerned the rotor is made to appear perfectly balanced.

The method of doing this is extremely simple, two small alternators (fig. 5) are driven round with the rotor and each is in series with one vibration generator. The voltage of each is adjusted so as to be equal, and of opposite polarity, to that of its own generator so that the resultant voltage of the pair is zero. It may be necessary to vary the phase to do this, and rotatable stators are provided for the purpose. When this adjustment has been made the effects of the actual unbalances of the rotor obviously do not in any way affect the rest of the electrical circuits which are connected across the outside of the alternator-generator combinations.

When, however, a calibrating weight is added to the rotor, the extra voltages generated are passed on to the rest of the circuit in the normal way and setting up and calibration can be carried out just as if the rotor were actually in perfect balance.

The practical procedure for calibrating is therefore to buck out the vibration generator voltages with the rotor in its normal state, then to shut down and add an unbalance to one plane only. The network circuit can then be adjusted until this has no effect on the meter. This unbalance is then removed and a known unbalance added to the other plane. With the rotor running, the other half of the network circuit is set so that the meter is again unaffected. The two network settings for isolating either unbalance are thus complete.

With the alternator still bucking out the

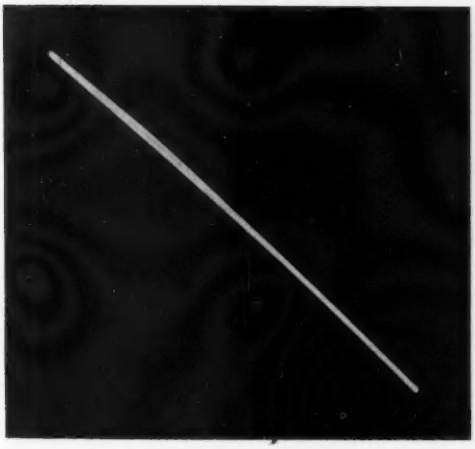

Fig. 8.—Oscillogram of alternator and vibration voltages in phase.

Fig. 9.—Oscillogram of alternator and vibration voltages out of phase.

inherent unbalance, the reading obtained from the known unbalance on one plane, with the network set so that the other plane has no effect, is one calibrating point. A straight line graph through zero and this point gives a complete calibration for one end.

Positioning is carried out in a similar manner using the known unbalance so that the relationship between alternator stator and rotor, and unbalance positions is known.

The known unbalance is then moved to the other balancing plane, the network is switched over and new calibrating and positioning records made for this plane.

Finally, the known unbalance is removed altogether and the two alternators mechanically declutched from the rotor. The machine is then ready for the actual balancing runs, during which the two alternators act only as an impedance in the circuit because they are stationary and not generating any voltages.

Balancing Procedure.

The foregoing description may have given the impression that the practical balancing procedure is a lengthy and complicated business. In actual fact the whole process, including calibrating, takes about one hour, and the machine can be worked by an operator who has no technical training.

The complete routine involves running the rotor up to the balancing speed five times, these runs are listed below and it should be realised that only one run is required (No. 5) if the rotor is similar to one previously balanced so that a calibration is available.

1. Run up and buck out the effect of each vibration generator by a small alternator (i.e. simulate perfect balance).
2. Fix a known unbalance to one plane, run up and set network circuit so that unbalance on this plane has no effect.
3. Remove the known unbalance of (2) and fix it or another known unbalance to the other plane. Run up and obtain a network setting so that unbalance on this plane has no effect. Switch to the network setting of (2) and the readings obtained are the positioning and calibrating points.
4. Remove the last unbalance and fit an unbalance to the original plane, switch the network to the setting of (3) and obtain the other calibrating reading. Calibration is now complete.
5. Declutch the two calibrating alternators and take readings of unbalance and position at both ends. The readings give the size and position of the balance weights required.

RESULTS OBTAINED.

As previously mentioned a complete calibration and balancing of a new type of rotor takes about one hour. This compares with the period of about 50 hours required by the trial methods previously used by a skilled operator. The greater part of the time in either case is taken in running the rotor up and stopping it.

The accuracy is found to be all that is required. A 20 or 30 ton turbo rotor is easily balanced to a tenth of an ounce at its periphery. The ultimate limits of the machine in this direction have not been required.

The angular position of the unbalance is normally found to plus or minus one degree, but this can be improved on if necessary.

The Co-ordination of Analytical Techniques in Industrial Research

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In this article the authors describe how in the Research Laboratories of The General Electric Co. Ltd., the various analytical techniques are co-ordinated. It is shown that information is provided on a considerably broader basis than usually results from conventional chemical analysis.

INTRODUCTION.

THE properties and behaviour of materials depend very largely on their chemical constitution and physical structure. In a research organisation, and in technical industry generally, it is therefore of paramount importance to have available the proper facilities for determining the composition, structure and other attributes of all materials of interest. In fact, modern industry relies at almost every stage of research, development and production on the results of what has been called broadly chemical analysis of materials used in, or in conjunction with, the product.

It is now becoming more widely appreciated that "chemical analysis" goes further than determining the percentage composition of a sample, usually expressed in some rather arbitrary way. For convenience, therefore, we shall assume it to refer to all those techniques and investigations which contribute to our knowledge of the structure and composition of materials. This field of investigation, embracing not only chemical methods, but also many techniques of investigation with modern physical tools, may appear to be too wide to be understood, let alone exploited, by any single analyst. It must be realised, however, that in parallel with this wider conception of analysis, the "analyst" himself is in course of transformation from an individual into a team of specialists, some of whom would have had no place in the traditional chemistry laboratory. Such physical apparatus as the viscometer, refractometer and optical microscope have long been considered as legitimate tools of the analytical chemist; it invokes no new principle to include also the X-ray and electron diffraction apparatus and the electron microscope, even if additional specialists are required to operate them and interpret the results.

CO-ORDINATION OF THE ANALYTICAL FACILITIES IN A RESEARCH ORGANISATION.

In a large research organisation the analytical section may possess all the necessary apparatus and facilities and have on the section staff the specialist chemists and physicists required for all analytical investigations. In many establishments this is the ideal arrangement since all analytical problems are handled in their entirety within the department under central supervision; also different techniques, which might be operated in a somewhat competitive if not antagonistic manner, if in different research departments, can be employed in a fully complementary and most efficient way, while the closest collaboration between all the staff concerned can be maintained continuously throughout the progress of the investigation.

In many large research organisations, however, techniques which are used wholly or partly for analytical investigations may, for various reasons, be situated and staffed in departments other than that devoted to chemical analysis. With proper co-ordination and organisation this need be no

disadvantage; in fact, the efficiency of the analytical services provided can be at least as high as in the single unit organisation described previously; it may even lead to a more useful type of service owing to the wider range of interests of staff in the extra-mural sections which are contributing to the overall analytical effort. It must be emphasised, however, that unless this co-operation is close and continuous, an unsatisfactory situation may develop in which some techniques are neglected through lack of appreciation of their potential contribution or, what may be more dangerous, are developed into independent competitive analytical services.

Fig. 1.—Part of the X-ray Analysis Laboratory at Wembley.

In the G.E.C. Research Laboratories at Wembley the analytical services are provided by an organisation of the second type, that is several departments possessing facilities which can make a useful contribution to analysis and analytical investigations co-ordinate these activities closely to form what is, in effect, a single analytical unit. Although this idea of the single analytical group has been an active principle at Wembley for over two decades, contact between the different analytical sections has, in recent years, been further improved by the introduction of certain regular liaison arrangements. In addition, more effective collaboration has been established between the analytical unit and the other departments in the Laboratories requiring its services. These more formal arrangements have been of value in so far as they are better suited to the increased analytical staffs and the greater diversity of problems arising from the increased size and scope of the Research Laboratories generally. However, they in no way prevent the continuance of the valuable informal interchange of ideas which, in earlier years, sufficed for the smooth running of the analytical work.

At this stage it may well be asked why the analytical facilities are distributed among various departments and what advantages accrue from this arrangement. The answer, in brief, is that some sections were established initially to study certain physical phenomena and undertake the measurement of relevant physical data. Their original function was certainly not visualised primarily as a contribution to analytical chemistry although this followed naturally and, it should be emphasised, at a time when it could still be considered as very much of a pioneering effort.

This non-analytical work has still continued to be of great importance in the Research Laboratories. For example the X-ray diffraction section has to undertake a considerable amount of pure and applied crystallographic research as distinct from analytical applications, while the spectrographic section is partly employed on studying the characteristic radiation from light sources and the spectral transmission and reflection properties of materials.

This duality of function may be no bar to efficient analytical service provided the liaison arrangements already outlined operate satisfactorily. It will now be apparent that transfer of the facilities to the analytical section proper would have an adverse effect on the non-analytical functions, while the third arrangement, viz. duplication of specialist staffs and elaborate equipment, would be both unnecessary and costly.

FUNCTIONS OF THE ANALYTICAL UNIT.

The work of the analytical unit is extremely diverse, both in nature and purpose; for convenience it may be considered as falling in the following principal categories:

(*a*) General analytical work for all departments of Research Laboratories on various materials used in research, development and testing. In this field there is also a small proportion of analysis for certain of the Company's Works. In the main it can be considered that

work in this category involves the application of known analytical methods.

(*b*) The general analytical investigation of new materials of interest to other departments of the Laboratories. Broadly this involves the determination of composition, structure, trace impurities, etc., of various samples of the material in an attempt to correlate these with functional properties of the material. This type of investigation may lead to a useful specification of the material concerned.

(*c*) Supplementary to the type of work described under (*b*), fundamental research in analytical methods may be necessary in order to deal with the problem as it develops.

(*d*) When desirable properties of a material have been formulated, the establishing of the analytical method most appropriate for routine control in connection with production.

(*e*) General " forward thinking " and exploration of new analytical techniques that may become of value in the future.

The method of initiating work in any of the above categories depends upon the magnitude and importance of the problem to be studied.

Where an investigation involving considerable effort is likely to be necessary, the matter is first discussed in its broader aspects by representatives of the analytical group and the interested parties who have submitted the problem ; subsequently more detailed discussion of the methods to be used can take place at a regular internal meeting of analytical section staffs.

For investigations of a minor character, or where the analytical work is straightforward, samples are submitted for analysis accompanied by notes giving as much useful technical and other information as possible. These notes, mentioned more fully below, serve as a useful aide-memoir when the problem is reviewed at the next regular meeting of analytical staffs.

The days are long past when it was thought sufficient, or proper, to submit say three samples, marked A, B and C, accompanied by the bare

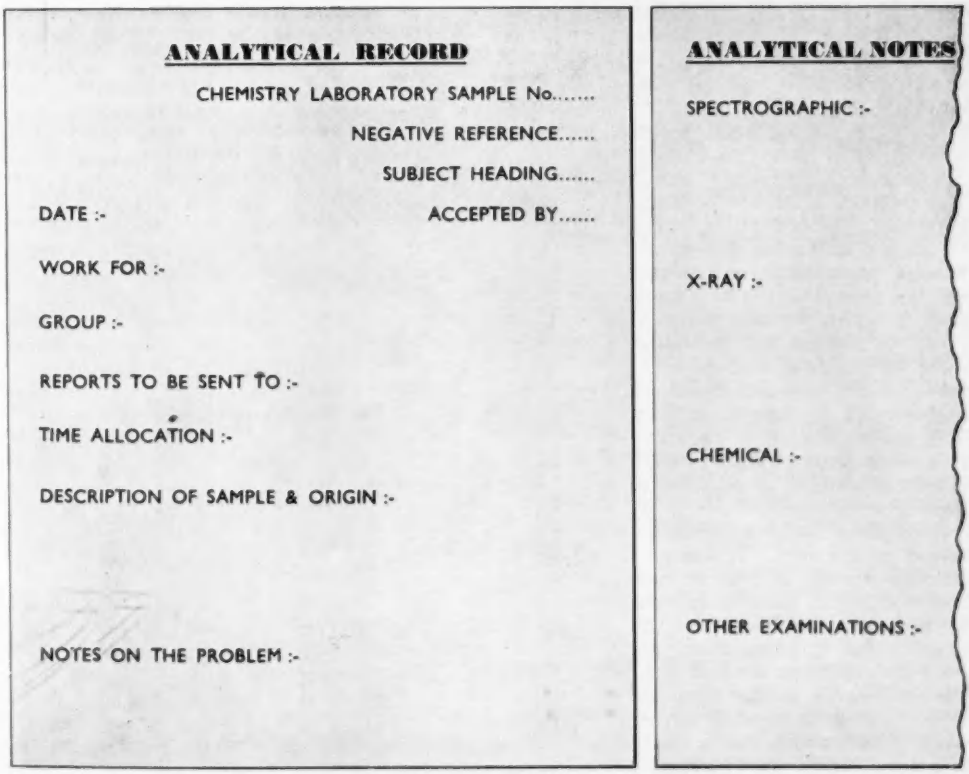


Fig. 2.—Analytical Record Form. Part (a) (*left*) is completed when the investigation is initiated ; (b) (*right*) forms a running record for the various analytical sections concerned.

request " please analyse these samples ". Such an approach would obviously not give the analytical group that information which is necessary to plan its work most efficiently; also the results obtained would not necessarily be those of most value to the department submitting the samples. Moreover, it is not now possible to submit samples of the same material independently to two or three analytical sections without revealing this fact to any of the analysts concerned. On occasion this could have been done in good faith in the hope of acquiring as much knowledge as possible but, in analytical work, the sum of the independent parts rarely gives as much information as the properly co-ordinated whole.

As mentioned above, samples submitted for analysis must be accompanied by written information and this is entered by the customer on the first section of a form which remains with the sample (or its derivatives) until all analytical work has been completed.

The two portions of this form are illustrated in fig. 2. The information required from the person submitting the sample is entered in the section headed " Analytical Record " which, as can be seen, covers various points of administrative interest. Special emphasis, however, is placed on " Notes on the Problem " particularly where the work is of non-routine character, as it is in a high proportion of the problems submitted. Where it is a matter of finding an explanation for an unusual phenomenon or resolving an unexpected difficulty, much help is given to the analytical group by a clear and full statement of the facts that have led the enquirer to believe that an analysis can be helpful to him. The analyst himself is then also in a much better position to make helpful suggestions as to profitable lines of attack.

Two other useful purposes are served by the form. It acts as a running record to which each analytical section adds its findings as they are obtained. At any moment the investigator can see what his colleagues have done on the problem up to that time and their notes for suggested further work. Also when the work is finally completed, which may be after a lapse of some time if the job has been difficult, the two sections of the analytical record sheet provide all the data for incorporation in a final formal report.

The sub-headings on the form under " Analytical Notes " refer to the main analytical sections concerned rather than to the specific technique employed. For example, the results of such physical tests as are normally carried out in the chemical section—conductivity, viscosity, etc.—may be entered under " chemical :—". " Other examinations " would include any useful information resulting from microscopy, spectrophotometry, metallurgical tests, observations of fluorescence, etc.

With this system, it is immaterial to which analytical section the sample and form are first submitted. If the proper information is entered on the form and supplied with the sample, the section which should undertake the first steps in the analysis will, in most instances, be obvious to the responsible analyst receiving the request. If necessary, the sample is then re-directed immediately to the appropriate section. In difficult and doubtful cases the sample is retained in the recipient section and the problem raised for discussion at the next regular analytical

Fig. 3.—Spectrographic determination of trace constituents; photographing the arc spectrum of the sample.

meeting. For urgent problems in this class, an *ad hoc* analytical group discussion can be convened immediately and the investigation started as soon as the analytical procedure has been agreed.

To sum up, this system gives the fullest opportunity for satisfying the two most important requirements for providing an analytical service. First, the background information about the problem that has led to the request for an analysis is available to the analytical staffs : this provides the incentive to discussion with the people concerned to determine if the analysis requested is likely to furnish useful information. In extreme cases it may not be needed at all ! Second, having been satisfied that the proposed analysis or investigation is justified, the analytical staffs have an established mechanism for ensuring that the most fruitful methods are employed for the solution of the problem.

POTENTIALITIES AND LIMITATIONS OF ANALYTICAL TECHNIQUES.

During the past few years the number of analytical methods available, in particular those using the newer physical techniques, has increased considerably. It must be emphasised, however, that no single one of these methods is pre-eminent ; each has its own particular sphere of applicability and will be found to be inappropriate or completely valueless in others. Claims regarding the merits and successes of any particular method or tool are, unfortunately, generally presented by enthusiastic specialists, who may have little interest or experience in other methods or who do not possess a good general analytical background. Assessment of the potential value to analysis of some of these newer techniques is thus not always easy. There is no doubt, however, that several of these newer methods have had spectacular success in certain fields ; for example, the application of infra-red absorption spectroscopy to the analysis of organic compounds has, on occasion, produced results where all other methods fail.

At the G.E.C. Research Laboratories the range of analytical activities is very wide, covering many fields of interest ; also the incidence of the work changes rapidly ; in fact, almost from day to day. The principal materials for which analyses are in frequent demand include : a wide range of metals and alloys in connection with metallurgical and other researches ; water, in connection with industrial and domestic water heating problems ; glasses ; furnace bricks and linings ; refrigerants ; fluorescent powders used in discharge lamps and cathode ray tubes ; rare metals and compounds ; mineral ores, in connection with ore dressing problems.

In these fields of interest, the two supplementary techniques of greatest value have been found to be X-ray crystallography and emission spectrography. The chemical section, using classical micro methods, semi-micro methods and various subsidiary techniques occupies its rightful place as the keystone of the whole analytical structure.

Fig. 4.—A semi-micro balance in use in the Chemistry Section. Many complete analyses are now carried out on samples weighing 50 mg. or less.

The main co-ordination thus takes place between these three sections while other techniques, e.g. absorption spectroscopy, electron microscopy and diffraction, special micro-methods of gas analysis, etc., are employed as required.

Table 1 gives a summary of the principal applications of emission spectroscopy and of X-ray analysis. This shows first those particular applications of the methods which are complementary to one another and to chemical analysis, and indicates in an approximate manner the dependence of the one technique upon the other. For the sake of completeness certain other applications of the two techniques have also been included in this Table. These latter applications, although apparently more in the nature of inde-

pendent functions of the respective techniques, will also contribute to the final picture of the nature and composition of the material under test.

Although the exact sequence of operations is not always the same, a spectrographic or X-ray diffraction examination will usually precede a chemical analysis. Not only are they, in general, more expeditious, but relatively small samples of material are required and, in the case of the X-ray diffraction, the sample is not necessarily destroyed by the test. If the preliminary examination is spectrographic, it provides a rapid qualitative analysis of the metals and some of the non-metals in the sample, thus providing a basis for planning the subsequent chemical analysis. The information obtained from this test is more than merely qualitative, for the elements may be classified as : major constituents, impurities of sufficient importance to figure in a chemical analysis and trace impurities. These last are often without significance, although they may in some materials be of outstanding importance.

A point to note in connection with qualitative analysis by chemical methods is that they frequently take as long as the quantitative examination, particularly if the sample has to be decomposed by fusion as in the case of silicates. In fact, it may not be possible to be certain that all the constituents of a substance have been enumerated unless a quantitative summation is obtained. In the absence of complete qualitative information the chemical analysis might be incorrectly planned and an arithmetically correct, but chemically false summation be obtained.

While on the subject of qualitative spectrographic test, it should be mentioned that, in using the normal procedures, elements such as oxygen, nitrogen, sulphur and the halogens are not normally detected.

A preliminary X-ray diffraction analysis will give much additional information about the sample. Provided the constituents of the sample exhibit some degree of crystallinity, these will be identified as the compound forms in which they occur in the sample. Small impurities and trace constituents will, in general, not be recorded. Combined with the spectrographic evidence already available, it will be seen that a fairly complete qualitative picture of the nature and form of the sample is now available. The material can now go forward for chemical analysis, if required, although the information

TABLE 1.

INTER-RELATION OF TECHNIQUES AND SOME SPECIAL APPLICATIONS.

Emission Spectroscopy		X-ray Analysis
Assistance in identifying materials giving unknown X-ray patterns or no pattern.		Identification of Crystalline Materials.
General qualitative examinations.	CHEMICAL ANALYSIS	Identifying residues and precipitates from chemical analysis.
Check of purity of chemical preparations.		Distinguishing polymorphic forms.
Testing to specification with chemically analysed standard.		Quantitative analysis of solid solutions.
Special applications to quantitative analysis.		Special applications to quantitative analysis.
Identification of traces and of minute samples.		Determination of crystal size or state of subdivision of a material.
		Detection of lattice distortion.
Identification of gases and vapours in low-pressure devices.		Determination of crystal orientation.

obtained at this stage may be a sufficient answer to many of the problems.

It should be mentioned that in some analytical problems a quantitative spectrographic or X-ray analysis may take the place of the chemical analysis as the final step. These quantitative techniques, however, require much preliminary work in order to establish the method and to make calibration curves with synthetic standards or chemically analysed samples. Their adoption, therefore, is generally justified only where a long run of samples of the same type is expected.

Where the spectrographic and X-ray methods provide more or less identical information, one or other will usually be found to have some advantage for each particular problem submitted. While on the subject of potentialities and limitations of these analytical methods, it is important to realise that in some circumstances it may be a real advantage to have a method of relatively low sensitivity. For example, the identification of a minute amount of deposited metal, which occurs as a film on the inside surface of a lamp or radio valve bulb, is a problem of common occurrence in our Laboratories. This problem is usually tackled spectrographically, the film being dissolved in a suitable reagent and used to impregnate a pure graphite rod which subsequently forms an electrode in an arc. Several metals may be revealed on the spectrogram, for example nickel, copper, iron and tungsten. Without making up synthetic standards and spending much time on the problem it may not be possible to state with certainty which is the major constituent. If, however, some of the film can be removed and submitted to X-ray analysis, only those metals which are major constituents of the film will, in general, be revealed.

Other considerations affecting the choice of method to be used will be apparent from the examples of special analytical problems to be discussed in the next section.

EXAMPLES OF "COMBINED TECHNIQUE" ANALYSIS.

The value of the X-ray diffraction pattern in identifying crystalline materials has already been mentioned, and in this connection it should be stressed that the great majority of materials possess sufficient crystallinity to give a characteristic pattern in the X-ray diffraction apparatus. Since no two pure chemical compounds have precisely similar atomic arrangements and since the diffraction pattern derives its precise form from the atomic architecture of the substance, it will be seen that it should be possible to identify any given chemical substance from its X-ray diffraction pattern, provided a sufficient reference library of standard patterns or known structural constants is available.

Consideration of the bewildering array of patterns likely to arise when applying the X-ray technique to a wide variety of problems emphasises the necessity of restricting the search among the standard comparison patterns to as narrow a field as possible in each case. This is where supplementary information from a spectrographic test is valuable, since it restricts the search to compounds of those elements detected by the spectrograph. Identification of the material is then complete when the X-ray pattern has been matched accurately with a known pattern of a substance whose composition is consistent with the spectrographic evidence. As an example, it was necessary on one occasion to identify a "fluffy" deposit found on the wall of a graphitising furnace. A characteristic X-ray diffraction pattern was obtained from the material, but this was not identified immediately and the origin of the sample did not provide any specific clue as to its probable nature. However, a spectrographic test showed that calcium was the only metal present and with this additional information, it needed only a short search of the X-ray index to obtain positive information that the material in question was calcium sulphide.

In the above example the spectrographic evidence, although of considerable assistance in speeding up the identification, was not absolutely essential. Although it might have involved a very long and arduous search, the correct result might well have been obtained without the result of the spectrographic test. If, however, the quality of the X-ray pattern were somewhat poor owing to the nature of the sample, the small amount available or through some slight instrumental defect, then positive identification by comparison of standard X-ray patterns would be much more difficult. Zinc sulphide and silicon, for example, give patterns sufficiently close to that of cuprous chloride to be confused with it under unfavourable conditions; in these circumstances the spectrographic test could be considered essential to remove any chance of ambiguity.

Fig. 5 shows the close similarity between the X-ray diffraction patterns of zinc sulphide and cuprous chloride. The clear distinction between the optical spectra of zinc and copper emphasises the usefulness of the subsidiary technique of spectroscopy.

Leaving the question of chemical identification of pure substances or mixtures of pure substances, there is a second class of problem where information from a spectrographic examination may be essential to the identification of a

material from the X-ray pattern. In the case of a solid solution of two materials, the X-ray pattern obtained consists of a single pattern and not of two superimposed patterns as in the case of a mechanical mixture of the two constituents. This single pattern is generally similar in character, but differs in dimensions from those of either of the two constituent materials. This is illustrated in fig. 6 which shows the diffraction patterns of two pure metals, copper and nickel and two alloys (solid solutions) of the two metals. The important point to note is the gradual change in the dimensions of the pattern as the composition of the alloy changes. This leads to an important application, viz. making quantitative determinations of alloy composition from measurements of the pattern dimensions. However, it will be appreciated that some other metals, also capable of going into solid solution with copper or nickel, will also produce changes in pattern dimensions. The result may be that copper alloyed with x per cent of metal A may give a pattern almost identical with that from copper alloyed with y per cent of metal B. This ambiguity is resolved immediately if a spectrographic examination has been made to determine if A or B is present.

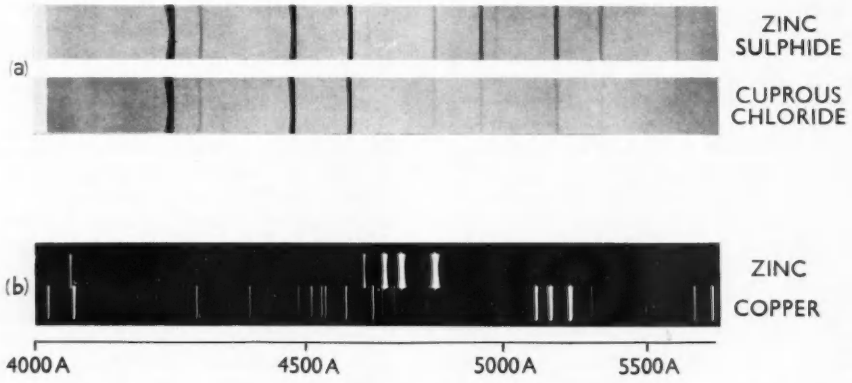


Fig. 5.—(a) X-ray diffraction patterns of zinc sulphide and cuprous chloride showing close similarity. A spectrographic test will resolve any ambiguity as shown in (b) optical spectra of zinc and copper.

Such an example actually occurred recently when some metal tube for radio valve components, stated to be nickel, was found to have unsuitable characteristics. A spectrographic examination showed that nickel and copper were both major constituents and, with this information, the X-ray diffraction pattern was interpreted as showing the metal to be a homogeneous alloy, approximately 80 per cent copper and 20 per cent nickel.

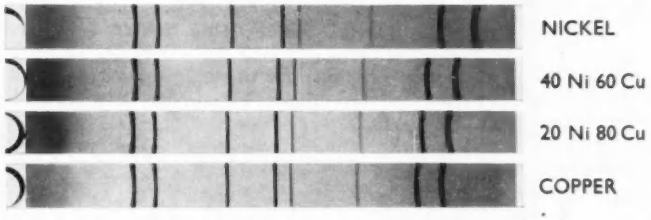


Fig. 6.—X-ray diffraction patterns of pure metals (copper and nickel) and alloys, showing the type of pattern obtained from solid solutions.

With similar co-ordination of the two tech-

niques it is frequently possible to identify compounds in which some degree of solid solution occurs. In natural minerals it frequently happens that there is some substitution of atoms of one element by those of another element, with consequent effect on the dimensions of the crystalline lattice. For example, X-ray examination of a magnetic sand from New Zealand showed that the material consisted essentially of a spinel type material similar to magnetic oxide of iron Fe_3O_4, but with lattice dimensions differing slightly from those of pure Fe_3O_4 suggesting that another constituent was in solid solution. Subsequent spectrographic examination demonstrated the presence of titanium as an appreciable constituent of the material. The lattice shift noted was consistent with the presence of titanium in solid solution and, coupled with the fact that no free titanium minerals were detected by the X-ray examination, the two tests provided complete identification of the material.

In very many problems the information supplied by spectrographic and X-ray examinations is insufficient and chemical analysis must follow as the next step in the investigation. This is often quite straightforward, particularly in view of the considerable information already available from the preliminary investigations which enables the analytical chemist to plan his procedure accordingly.

In the case of very complex mixtures, perhaps containing unusual elements, the supplementary techniques can again be used to check the purity of the separations made during the chemical analysis. This is a most valuable procedure and its importance does not appear to be as widely appreciated as it deserves.

The X-ray diffraction examination is undoubtedly the best way of checking the nature and form of a precipitate obtained during chemical analysis. Not only can the purity of the precipitate be checked for freedom from contamination with other constituents of the material being analysed, but information can be obtained as to whether the precipitate is in the best form to be used as a basis for a gravimetric determination.

As an example, in the chemical analysis of a glass, where the result was required to a high degree of accuracy, the precipitate representing the aluminium oxide was examined by X-ray diffraction. It was found that although the precipitate consisted essentially of the oxide of aluminium without detectable contamination, the crystal form of the material was of the gamma type with ultimate crystal size in the colloidal range. A report was accordingly made to the chemical section that " although the separation was pure, ignition had not been sufficiently prolonged or been carried out at sufficiently high temperature to effect conversion to the alpha structure which is normally desirable for gravimetric determination ".

In the above example all that was necessary to rectify matters was a slight modification to the final treatment of the precipitate before weighing. In another instance, X-ray examination of what was thought to be alumina showed that the material was actually magnesium tungstate ; here it was necessary to change the chemical procedure in order to obtain a proper separation.

Fig. 7.—Analysis of nickel for radio valve cathodes in progress in one of the Chemical Laboratories.

Spectrographic examination of precipitates can also be of value if it is required to check the purity of non-crystalline preparations or assist in identifying materials giving unusual X-ray patterns.

Another interesting application occurred recently in connection with the analysis of a complex phosphor used in fluorescent lamps. This material contained high proportions of both zinc and cadmium and it was required to know the relative proportions of these two constituents quite accurately. The chemical separation proved difficult, but after some study a satisfactory method was obtained based on a very old procedure of Fresenius, and the purity of the separations so obtained was checked by X-ray examination. The relative proportions of zinc and cadmium as determined by this chemical analysis were 1.48:1 expressed as the ratio of the sulphides $ZnS : CdS$. While this work was in progress an independent alternative method was

being investigated which involved an ingenious use of X-ray diffraction technique. The sulphides of zinc and cadmium can form solid solutions over the complete range of composition from 100 per cent *ZnS* to 100 per cent *CdS*. As already explained, the X-ray pattern of such a solid solution is intermediate between those of the pure components and the displacement of the lines in the pattern can be measured and used to determine the composition of the solid solution. The zinc and cadmium from the sample were precipitated together as sulphides, a simple chemical operation, and were then given an appropriate heat treatment to bring them into homogeneous solid solution. Calculation from measurements of the X-ray pattern of this material gave the ratio *ZnS* : *CdS* as 1.47 : 1, in excellent agreement with the previous chemical determination. This example suggests interesting possibilities in determining the relative proportions of isomorphous materials whose chemical separation is difficult or well nigh impossible.

The foregoing discussion and the examples quoted have emphasised the value of a properly integrated analytical service unit in a research organisation. It has been shown that in many instances the complete answer to the analytical problem is achieved only through co-ordination of various complementary methods of investigation. As a result, not only is the determination of precise chemical composition facilitated, but information regarding other qualities of the material, such as state of combination, crystal size and lattice strain, becomes available. This more complete picture of the composition and qualities of a material can now be accepted as a legitimate aim of " chemical analysis " in the broader sense. It should be appreciated, however, that this newer conception of analysis in no way underestimates the value of the various standard procedures and techniques which are fully recognised in the Laboratories and are in continuous use on a variety of analytical problems.

CONCLUSION.

Many years' experience in running the analytical group in a large research organisation has shown that the conditions under which the group may operate most efficiently, and to the greatest benefit of the Laboratories as a whole are :

First, there should be full and continuous collaboration between the analytical group and the other sections of the Laboratories requiring its services. This implies, among other things, that the analytical staff may often make the decision as to which line of analytical work will be most fruitful in assisting with the problem under investigation.

Second, the different sections comprising the analytical group should themselves act as one unit and, wherever possible, combine their forces so as to enhance the value of the results obtained. The broadest view should be taken as to what properly constitutes analytical data.

Third, opportunities should be available for research in analytical methods in order to equip the group as fully as possible for meeting new and novel demands for analytical services.

NEW PRODUCTS

SHIPBOARD SHAVER OUTLET

These units were first supplied to the Canadian Pacific Steamship Company for the "Empress of Scotland" to enable American dry shavers to be used on the ship's electric supply.

The adaptor comprises a white enamelled metal box with resistance selector switch and universal outlet socket. The seven switch positions, each marked with the name of a shaver, give the correct voltages for the shavers indicated. A cord and connector enable the adaptor to be plugged in to the nearest cabin point. In addition to the American shavers, the adaptor will also take the British standard 5 amp. and the Continental thin pin 10 amp. plugs.

HIGH BAY LIGHTING FITTING

This fitting has been designed specially for use with the new Osram 1 kW mercury lamp. It consists of an anodised aluminium reflector mounted below a vitreous enamelled canopy with large ventilation slots.

The canopy also carries an auxiliary aluminium reflector cone and skeleton G.E.S. Saaflux type lampholder. A heavy duty Saaflux top, tapped 1 in. E.T., is fitted. The reflector is detachable from the canopy for maintenance without disturbing the lamp; a clip-on $\frac{1}{8}$-in. mesh wire guard is included.

The downward distribution is designed to secure the best utilisation of light when the fitting is mounted at a considerable height. Some upward light is emitted through the ventilation slots in the canopy. With the wire-mesh guard in position the light output ratio is 65 per cent. The convection air stream helps to retard the deposition of dirt on the reflecting surfaces.

NEW TELEVISION RECEIVER BT 2147

The new BT 2147 table television receiver in a plastic cabinet is an inexpensive instrument of high efficiency designed to bring television reception within the reach of as many people as possible. A T.R.F. circuit is employed, with three signal frequency amplifiers common to sound and vision channels followed by individual sound and vision amplifiers preceding the demodulators. The R.F. chassis is interchangeable in a matter of minutes to render the receiver suitable for either the London or Midland television frequencies.

A 9 inch aluminised cathode ray tube gives a brilliant picture which can be viewed in comfort in normal room lighting. Full gradation and detail are ensured by the use of a video amplifier stage having a level overall response from zero to 3 Mc/s. In normal daily use only two controls —"picture brightness" and "sound volume"—require adjustment. Permanent magnet focusing and stable time-base and synchronising circuits ensure that the pre-set controls will very rarely need attention. The set is suitable for A.C. or D.C. mains between 200 and 250 volts.

AUTORADIOGRAM BC 9239

Although moderately priced, the BC 9239 incorporates the features found in more expensive models, such as an automatic changer capable of handling up to ten 10 inch or 12

inch records; a 10 inch loudspeaker giving a powerful, undistorted output, and a handsome walnut cabinet with storage space for records.

The three-wave-band radio receiver covers 16-5-50 metres, 192-550 metres and 1,000-2,000 metres. Wave-band selection is by means of a push button. Sockets are provided for connecting an external loudspeaker. Reproduction is of excellent quality over the entire audio frequency range, and a tone control enables the output to be adjusted to suit individual tastes.

TELEVISION CATHODE RAY TUBES

The latest aluminising technique is now being used in 9 inch magnetic tubes, giving a vastly increased life expectation before ion burn becomes evident. The aluminium coating to the screen also gives increased brightness and contrast under most conditions of use.

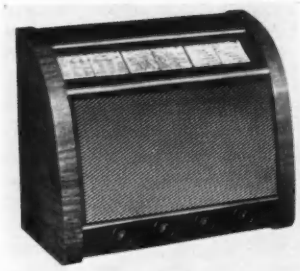
A 12 inch tube with aluminised coating is also in limited production and will shortly be followed by a series-run heater type.

MELLOW FLUORESCENT LAMPS

Three new sizes of the Osram Mellow fluorescent lamp have been introduced so that the complete range is now: $1\frac{1}{2}$ ft. 15 watt, 2 ft. 20 watt, 2 ft. 40 watt, 3 ft. 30 watt, 4 ft. 40 watt and 5 ft. 80 watt.

NEW RADIO RECEIVERS

BC 5639 for A.C. mains; BC 6638 for D.C./A.C. mains. These are three-wave-band table model receivers in attractively styled walnut veneer cabinets covering 13·5-50 metres, 187·5-550 metres and 1,000-2,000 metres. Wave-band indication is given by increased illumination of the scale in use, the remainder being dimly lit. Sockets are provided for a gramophone pick-up and an extension loudspeaker. A frame aerial built into the cabinet enables the receiver to be used for local station reception without an external aerial and earth.



NEW VALVES

The type U 37 is a high voltage rectifier in miniature size designed for providing the E.H.T. voltage for television cathode ray tubes. Special features are its small size and low heater wattage.

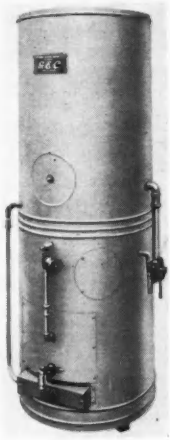
The type N 37 is an output pentode in miniature size for sound and frame time-base output stages in series-operated television receivers, designed for use with 0·3 amp. valves in a series heater chain. It replaces the KT33C in these applications.

INTERNALLY COLOURED SIGN TYPE LAMPS

These lamps, which have many applications for exterior decorative lighting, now have the colour applied to the inside of the bulbs by a new process which much improves their appearance when illuminated by reason of the even coating thus achieved. Furthermore, the colour being on the inside is unaffected by the weather. Another advantage of the new process is that the pigment will not flake off and cause failure by dropping on to the filament. Standard colours are red, blue, orange, green, yellow and white.

STORAGE BLOCK STEAM RAISER WITH WATER HEATER HO 5100.

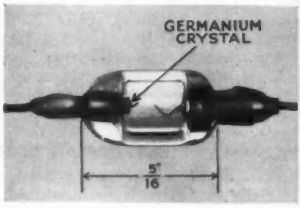
The HO 5100 storage block steam raiser with water heater provides an automatically controlled simultaneous



supply of steam and hot water. It has been designed primarily for use on dairy farms and will provide sufficient steam for a lagged sterilising chest up to 27 cu. ft. capacity, and for three or four milking clusters or churns. Provided the demand is not too severe, the unit may also be used with a two-unit recording milking plant, or for steel utensils in an unlagged 27 cu. ft. chest. The water heater has a capacity of 20 gallons which, when diluted with cold water, will provide 25 to 35 gallons of hot water for washing up, udder washing, etc.

The electrical loading is 1 kW each for the block and water heater, so that if steam only is required in the morning and hot water in the afternoon, the maximum day load will not exceed 1 kW. The maximum pre-heating period necessary for the steam raiser is 12 hours. An external control enables the rate of steaming to be varied between 18 and 60 lbs. an hour. With the standard 8 ft. 6 in. stand pipe the operating pressure is 4 lbs. per sq. in., but higher pressures, up to 10 lbs. per sq. in. with a 23 ft. stand pipe, are obtainable provided they do not exceed the feed water pressure. Steam pressure is regulated by a de-superheating device, which also pre-heats the feed water.

The 20 gallon pressure type water heater, above the steam raiser, is equipped with an apparatus plate in which are mounted a 1 kW embedded, withdrawable type immersion heater and an adjustable rod type thermostat to control the temperature. The complete unit is encased in a sheet steel cylinder finished in best quality stoved mottled grey enamel.



GERMANIUM CRYSTAL RECTIFIERS

These very small rectifiers, which are exceptionally robust and long-lived, are now available in the following range of standard types.

GEX 99 Non-linear circuit element : spark quench, simple crystal receiver.

GEX 33 For low impedance circuit: vision detector.

GEX 44 For medium impedance circuits: sound limiter.

GEX 45 For high impedance circuits: detector in narrow band amplifiers.

GEX 55 For higher impedance circuits than GEX 45: probe voltmeter.

TECHNICAL LITERATURE

A DIGEST OF RECENT BOOKS, ARTICLES AND PAPERS, BY MEMBERS OF THE G.E.C. AND ITS ASSOCIATED COMPANIES.

FREQUENCY MODULATION OF AN OSCILLATOR (377).*

By M. R. Gavin (Research Laboratories).

Wireless Engineer, Vol. XXXV, September, 1948.

A simple method of increasing the frequency deviation of an oscillator by means of a suitably adjusted coupled circuit, is described.

INTERELECTRODE CAPACITANCE OF VALVES (389).*

By B. L. Humphreys and E. G. James (Research Staff of the M.O. Valve Co. Ltd. at the G.E.C. Research Laboratories).

Wireless Engineer, Vol. XXVI, January, 1949.

This paper presents measurements, made at a frequency of 1 Mc/s, of the grid-to-cathode and the grid-to-anode capacitances of triode valves. These valves are all of a common basic electrode structure, in which the active elements are essentially plane. The measurements do not quantitatively confirm the theoretically predicted changes and indicate that the geometry of the grid has a marked influence on the change of the grid-to-cathode capacitance.

A STUDY OF CONFIGURATION CHANGES IN GLASS BY MEANS OF DENSITY (421).*

By R. W. Douglas and G. A. Jones (Research Laboratories).

Trans. Soc. Glass Techn., Vol. 32, 1948.

Changes of density with time in the transformation range have been studied in vitreous silica, a borosilicate glass and a soda-lime-silica glass. Previous papers have drawn attention to the close analogy between the atomic structure of glasses and liquids, and the results of the present experiments are interpreted in the light of that analogy.

THE MEASUREMENT OF LIGHT AND COLOUR (414).*

By G. T. Winch (Research Laboratories).

Proc. I.E.E., Vol. 96, Part II, No. 51, June, 1949.

It is shown that the C.I.E. specification of the "Standard Observer" has not only facilitated visual photometry and colorimetry, but is the foundation on which physical photometry and colorimetry have been developed. The types of photocells used, and the techniques which have ultimately enabled the C.I.E. "Standard Observer" to be realised in practice, both in photoelectric, photometers and in colorimeters, are described, together with other examples of special forms of photoelectric photometers.

THE DEVELOPMENT OF Q-METER METHODS OF IMPEDANCE MEASUREMENT (416).*

By A. J. Biggs and J. E. Houldin (Research Laboratories).

Proc.I.E.E., Vol. 96, Part III, No. 42, July, 1949.

The Q-meter (or magnification factor meter) has become the recognised instrument for all kinds of r.f. impedance measurement. The resonant measuring circuit which forms the basis of such instruments may be excited from the oscillator source in different ways. In this paper, instruments have been classified into low-impedance and high-impedance injection types, according to the systems employed. A section of the paper is devoted to the definition of Q and the relationship between the quantities obtained on differing bases clarified.

PREVENTION OF ACCIDENTS ARISING FROM ELECTRICAL WORK (418).*

By J. C. Cornwell (Research Laboratories).

Conference on the Origins and Prevention of Laboratory Accidents, November, 1948.

The safety precautions taken in the Research Laboratories of The General Electric Company, Limited, are described, and the experience gained in these Laboratories over twenty-four years is summarised.

NEW ZINC SULPHIDE PHOSPHORS ACTIVATED BY PHOSPHORUS (423).*

By A. H. McKeag and P. W. Ranby (Research Laboratories).

Jour. Electrochem. Soc., Vol. 96, No. 2, August, 1949.

This paper describes a new series of zinc sulphide phosphors, in which the activator is the non-metal phosphorus. This gives a range of unsaturated colours, varying from pale blue to yellow as the phosphorus content is increased. The physical and chemical characteristics, as well as the methods of preparation, of the new phosphors are fully described.

ALKALINE EARTH HALOPHOSPHATES AND RELATED PHOSPHORS (424).*

By H. G. Jenkins, A. H. McKeag, and P. W. Ranby (Research Laboratories).

Jour. Electrochem. Soc., Vol. 96, No. 1, July, 1949.

A class of new phosphors of great technical importance is described, which enables white light to be obtained in fluorescent lamps from a single chemical compound. The new materials are alkaline earth halophosphates activated with antimony and manganese. A short account of the structure of the phosphors is given. The mechanism of luminescence in these phosphors and some of their performance characteristics are discussed briefly.

THEORY OF THE HIGH-PRESSURE HELIUM DISCHARGE (428).*

By V. J. Francis (Research Laboratories).

Phil. Mag., Ser. 7, Vol. XL, October, 1949.

The method developed in recent papers for calculating the characteristics of the high-pressure discharge is extended to helium. The properties of the helium discharge derived in this way are compared with those of high-pressure mercury vapour.

STUDIES IN THE ELECTRON MICROSCOPY OF NICKEL-CHROMIUM ALLOYS (429).*

By B. S. Cooper and G. A. Bassett (Research Laboratories).

Institute of Metals Symposium, November, 1949.

Several methods have been employed for the preparation of nickel-chromium alloy specimens for electron microscope examination. Silica replicas for specimens etched with bromine-methanol reagent appear to be the most satisfactory.

TESTS OF TRANSMISSION LINE TOWERS (434).*

By H. W. B. Gardiner and W. H. Gomm (Research Laboratories).

The Structural Engineer, January, 1950.

A transmission tower, though in essentials a fairly straightforward lattice structure to which formal methods of design may be applied, has several features of unusual

*** A limited number of reprints is available of those papers marked with an asterisk. Copies may be obtained on application to the Editor, G.E.C. Journal, Magnet House, Kingsway, W.C.2.**

interest. Tests of such towers are described in this paper, and are all routine acceptance tests of commercial designs to check their suitability to meet specified requirements.

TESTING STATION RESTRIKING VOLTAGE CHARACTERISTICS AND CIRCUIT BREAKER PROVING

By J. S. Cliff (Witton Engineering Works).

A paper read at the Conférence Internationale des Grands Réseaux Electriques à Haute Tension, Paris, Session 1950.

To assign a breaking capacity rating to some forms of circuit breaker it is necessary to consider the restriking-voltage severity of the test circuit. This report describes the results of an investigation into the restriking-voltage characteristics of the testing stations of the Association of Short-Circuit Testing Authorities (A.S.T.A.), made to collect data which can be related to system conditions in order to reach a standard of restriking-voltage severity for proving circuit breakers.

To deal with the multi-frequency wave-forms which are obtained from some of the circuits an empirical method of evaluating the equivalent severity for such waves was evolved, and details of the method are given.

The characteristics of the test plants are given for the circuits corresponding to standard voltage and MVA ratings, and brief recommendations are made for the rating and testing of circuit breakers.

A list of definitions used in the investigation is included.

STREET LIGHTING COSTS.

By N. W. Wood (G.E.C. Exterior Lighting Department).

The Electrical Times, August 26th, 1948.

The paper discusses the difficulties of finding a way of evaluating the costs of different forms of street lighting.

It then describes a possible method and shows how to produce diagrams from which comparisons of running costs can be made between installations using different illuminants but producing the same light on the road in terms of lumens per 100 ft. linear.

SOME ASPECTS OF AGRICULTURAL AND HORTICULTURAL ELECTRIFICATION IN NORTH AMERICA

By F. E. Rowland (Agricultural Department).

Jour. I.E.E., December, 1949.
Jour., I.B.A.E., Vol. VI, No. 4, October, 1949.

Summary of a lecture describing a visit to the United States and Canada in 1948. A description is given of the applications of electricity to agriculture and horticulture, and a comparison is made between the technique and development in Britain and North America. The extent of development in this country bears favourable comparison with, and in some instances leads, that in America.

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